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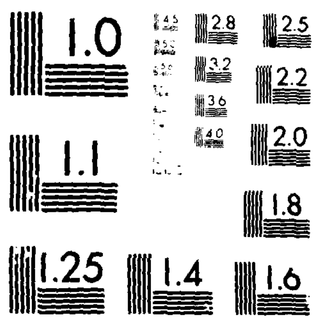

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POTENTIAL APPLICATION OF BIOMASS TECHNOLOGY AT NATIONAL SPACE TECHNOLOGY LABORATORIES AND MISSISSIPPI ARMY AMMUNITION PLANT

LEVEL II

FINAL REPORT 1980

PREPARED FOR

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

CONTRACT NO. DAAK 10-78-C-0268

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This study was initiated to evaluate the feasibility of utilizing a common biomass (energy wood) system to produce energy for use at NASA's National Space Technology Laboratories (NSTL) and the proposed Mississippi Army Ammunition Plant (MSAAP) to be established at NSTL.

The study investigated: the form and quantity of energy required at NSTL and MSAAP; the amount and characteristics of the available energy wood supply; the conversion technology; the legal and environmental issues

20. (continued)
associated with the operation of an energy wood plant; and the economics of an energy wood plant.

If an energy wood system were designed to replace the projected NSTL/MSAAP 1983 consumption of natural gas, fuel oil and coal, it would be sized to generate 359,000 lb/hr (0.45 kg/sec) of hot water, 28.3 x 10^6 Btu/hr (8.3 MW) of product heat energy, 140,000 lb/hr (0.18 kg/sec) of steam and 10 MW of electric power. The annual fossil fuel energy usage would be 1.5 x 10^{12} Btu (1.6 x 10^{15} J). Sufficient wood to meet this energy requirement is available in close proximity to NSTL/MSAAP in the forms of trees, mill residue and harvesting residue.

Three energy wood plants were designed in order to establish a basis for estimating the cost of producing energy from wood. All were based on utilizing established technology to generate steam in spreader stoker type wood boilers. The first was designed to produce the NSTL hot water requirements replacing the consumption of natural gas. The second plant was designed to generate the NSTL hot water requirements and co-generate 2 MW of electric power. The third plant was designed to meet the MSAAP steam requirements.

Environmental issues involve the land amelioration practices necessitated to insure a constant energy wood supply and the ultimate disposition of the products of wood combustion. The long term effects of proper implementation of the harvesting and reforestation plan proposed will result in an upgraded, faster growing forest and improved wildlife hapitate. The products of wood combustion are more environmentally acceptable than of most fossil fuels. Wood is virtually sulfur free, NO_x emissions are low, the ash produced can be utilized as a soil enhancer and wood is not subject to leaks and spills.

The ultimate legal issue involves the procurement of a reliable interim supply of energy wood. A statutory grant enables NASA to enter into an exchange agreement to utilize higher value sawtimber to procure increased quantities of lower value energy wood. It is imperative that NSTL not be credited with the sale of sawtimber since such revenues would go to the Treasury Department and NSTL/MSAAP would lose the benefit of the bargin.

The results of the economic analysis of the three NSTL/MSAAP energy wood systems are as follows:

	NSTL Hot Water	NSTL Hot Water and Power	MSAAP Steam
Capital cost	$11,022,000	$14,373,000	$23,105,000
Cost avoidance	0	0	8,330,000
Life	20	20	20
Salvage value	0	0	0
First year savings	$ 2,390,000	$ 2,787,000	$ 1,156,000
Payback	4.6	5.2	-
ROI	22.8%	20%	6.8%

Given the advantages in the economics and to the environment of operating a biomass to energy system at NSTL/MSAAP, it is recommended that a follow up design study to this study be conducted.

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EXECUTIVE SUMMARY

The U.S. Government, like other large users of fossil fuels, is investigating alternative energy resources. The NASA NSTL and the MSAAP are located in the forest area of southwest Mississippi. Since the government owns and leases over 130,000 acres (526 km^2) of forest, the potential for utilizing biomass (energy wood) to supply some of the energy requirements for NSTL/MSAAP is apparent. The objective of this program was to assess the technical and economic feasibility of utilizing a biomass system to produce energy for use at the NSTL/MSAAP.

The program was divided into seven tasks which allowed the following approach to be used.

1. Survey the NSTL/MSAAP energy requirements.
2. Determine the energy wood supply.
3. Survey the biomass-to-energy conversion equipment.
4. Evaluate the equipment.
5. Select the optimal system for each energy product mix.
6. Determine the system cost.
7. Perform an economic analysis.

In 1978, NSTL consumed more than 1.2×10^{12} Btu (1267×10^{15} J) of energy in the forms of natural gas, electric power and diesel fuel. In 1983, consumption for natural gas and diesel fuel is expected to level out at 416×10^9 Btu (439×10^{12} J). The MSAAP (peacetime) requirements for coal and diesel fuels are projected to remain constant at 416×10^9 Btu (439×10^{12} J). The quantities of natural gas, diesel fuel and coal projective to be consumed in 1983 are shown below. The forms of energy produced by the consumption of fossil fuels and utilized by NSTL/MSAAP are tabulated below.

Energy Requirements for NSTL/MSAAP (1983)

	NSTL		MSAAP	
	Quantity	Energy	Quantity	Energy
Diesel Fuel	152×10^3 gal ($.575 \times 10^3$ m^3)	21×10^9 Btu (22×10^{12} J)	1.3×10^6 gal 4.9×10^3 m^3	176×10^9 Btu (186×10^{12} J)
Natural Gas	395×10^6 ft^3 11.2×10^6 m^3	395×10^9 Btu (417×10^{12} J)	-	-
Coal	-	-	10×10^3 tons (9×10^6 kg)	240×10^9 Btu (253×10^{12} J)
Subtotal	-	416×10^9 Btu (439×10^{12} J)	-	416×10^9 Btu (439×10^{12} J)
Total	832×10^9 Btu/yr (878×10^{12} J/yr)			

NSTL/MSAAP Energy Requirements (1983)

Fuel Type	Use	Avg. Monthly Usage
Natural Gas	Hot water	30,000 MCF (849,600 m^3)
Electricity	Lights, testing, manufacturing	3 - 4 m KWH (10.8-24.4 TJ)
Oil (No. 2)	Heat treatment, diesel generators, incinerators	208,000 gal (787 m^3)
Coal	Steam	830 tons (756 x 10^3 kg)

Energy wood is available to NSTL/MSAAP in the forms of trees; logging residue not utilized from harvesting operations in the area; and mill residues from saw mills, logging, pole and paper operations. In 1978, the amount of energy wood available to NSTL/MSAAP was estimated to be 921 x 10^3 tons (827 x 10^6 kg) equivalent at 100% efficiency to 7.65 x 10^{12} Btu (8.08 x 10^{15} J). This value includes the total NSTL forest and the logging and mill residues from within a 50 mile (80 km) radius of NSTL. After 25 years of converting the NSTL forest to an energy plantation, the sustainable energy wood available from 986 acres harvested annually (4 km), plus the same quantity of logging and mill residues from within a 50 mile (80 km) radius of NSTL is estimated at 541 x 10^3 tons (491 x 10^6 kg) or 4.62 x 10^{12} Btu (4.88 x 10^{15} J). This amount of energy wood would more than sufficiently supply the requirements for NSTL/MSAAP.

Of the several processing options which may be applied to the conversion of biomass to energy, only the ones which fell into the direct combustion and pyrolysis catagories were considered advanced enough to be applicable to NSTL/MSAAP. The design criteria for wood to energy technology are listed, below.

Commercial availability - an operating unit must be available for evaluation.

Reliability - the equipment must be able to operate as a utility plant with the present NSTL system as a spare system.

Energy requirement - sizes to replace various combinations of energy products will be evaluated.

Feedstock - fuel will be green wood from NSTL forest supplemented by mill and harvest residue.

Equipment - systems should make practicable use of existing NSTL equipment

Environmental impact - systems must meet Mississippi air and water standards.

Location - close proximity to energy user.

Spreader stoker type furnaces for direct combustion of wood were selected as the equipment to best meet all the design criteria. Pyrolysis systems, although conceptually attractive because they produce oil and gas fuels, have not been commercially demonstrated, nor have the firing characteristics of the fuels produced been adaquately investigated.

Three different wood plants were designed for NSTL/MSAAP; one which produced the NSTL hot water requirement, one which produced the NSTL hot water requirement and co-generated 2 MW of electric power and a third designed to produce steam for MSAAP users. All three plants included wood-fired spreader stoker boilers to produce steam. In the NSTL hot water generator, the steam was utilized in a direct contact heat exchanger to generate hot water. In the NSTL hot water and power plant, superheated steam was exhausted through a backpressure turbine. The exhaust steam was then utilized in shell and tube heat exchangers to generate hot water. In the MSAAP, the steam produced was the required product.

The estimated capital investments for the energy wood hot water generator and the energy wood hot water plus power plants were $11 million and 14.4 million, respectively. The estimated first year savings in natural gas was $2,390,000 and $397,000 in power. These savings were based on natural gas at $6.05/MCF ($.22/m^3) and power at $.065/kw in 1985. The payback periods for the two systems, defined as total capital investment divided by first year fuel savings are 4.6 and 5.2 years, respectively. The ROI based on the total plant investments for these two plants are 22.8 and 20%, respectively. The difference in the cost of these two plants can be taken as the cost to generate electric power from energy wood at NSTL/MSAAP. Therefore the equipment cost to generate 2 MW of electric power is $1700 per kW. This cost of electric power generation is perhaps three times that of a public utility. However, for a small, dedicated facility, it may not be unreasonable. The total capital investment for the MSAAP energy wood steam system is $23.1 million in 1983 dollars. The plant was sized to MSAAP mobilization requirements. The cost of the steam generated is $18.00/1000 lbs ($.04/kg) at peacetime operating levels, and $8.60/1000 lbs ($.02/kg) for mobilization operation. The large difference in cost between peacetime and mobilization modes is due to the fact that the plant was designed for mobilization operation which is much larger than the peacetime mode. The fixed charges which are functions of the capital investment are the same for both modes of operation, resulting in a heavy burden during peacetime operation when half the equipment sits idle or is operating at less than optimum capacity. The ROI based on a cost avoidance of eight million for a comparable coal plant is 6.8%.

Implementation of the 25 year forest management plan proposed will eventually result in a sustainable energy wood production in excess of that required to support either one of the NSTL hot water plants plus the MSAAP steam plant. However, during the initial years of operation, procurement of mill or harvest residues will be necessary. Reliable supplies of energy wood can be contracted through large paper companies in the NSTL area. These agreements can also include the management of NSTL forest and trade agreements exchanging NSTL sawtimber, a high value commodity, for equal values (larger quantities) of mill or harvest residues (energy wood). Sale of the sawtimber to facilitate procurement of energy wood is unfeasible. Revenues derived would go directly to the Treasury Department and NSTL would lose the benefit of the bargin.

Implementation of the forest management plan and operation of an energy wood plant at NSTL/MSAAP will also result in constantly increasing operating cost savings relative to comparably sized fossil energy plants. Although the value of energy wood will be subjected to inflation similar to oil and natural gas, at NSTL the amount of sawtimber per acre of forest will be constantly increasing because of growth. Therefore the energy wood fuel annual expense minus the sawtimber credit will decrease while oil or natural gas annual expenses will constantly increase.

In summary, implementation of a forest management plan and energy wood plant at NSTL/MSAAP will result in the following: Lower operating expenses for production of NSTL required hot water and MSAAP required steam; the procurement of a reliable source of fuel; utilization of a fuel resource that is virtually sulfur free and without ash disposal problems; utilization of a fuel that may potentially be supplemented with waste paper; and the establishment of a forest management plan on government land.

INTRODUCTION

Like other large energy users, the U.S. Government is looking for fuel sources to supplant fossil fuel reserves. Currently, at the NASA National Space Technology Laboratories (NSTL) in Mississippi, an Army ammunition plant is under construction. The Mississippi Army Ammunition Plant (MSAAP) will be located on the northern portion of the NSTL fee area and will consist of various manufacturing complexes.

The National Space Technology Laboratories (NSTL) is located in the dense tree growth area of southwestern Mississippi overlooking the East Pearl River (see Figure 1). The 16 year old facility consists of 13,000 contiguous acres (52.6 km^2) of government owned land called the fee area surrounded by a 120,000 acre (490 km^2) buffer zone which has been leased by the U.S. Government for 99 years starting in 1962. This lease allows the government to control utilization of the lands in the buffer zone which is 90% owned by three major paper companies: Crown Zellerbach, St. Regis and International Paper Companies. The U.S. Government owns an additional 7500 noncontiguous acres (30.4 km^2) in the buffer region, 25% of which is leased to private individuals for cattle grazing and other agricultural uses. Most of these leases will expire between 1979 and 1980. The remainder of the buffer zone is owned by private individuals in small parcels. A land ownership map of NSTL is shown in Figure 2.

NSTL consumes significant quantities of fossil fuels in the operation of a variety of test facilities, laboratories and offices. Presently NSTL utilizes natural gas for approximately 50% of its non-transportation energy requirements and electricity for the remaining 50%. Two natural gas fired heating plants produce high temperature hot water (HTHW) for space heating, cooling, and domestic hot water.

In 1977, NASA sponsored a preliminary study of the potential of energy wood as an alternative fuel source. The study evaluated the application of a Tech-Air wood pyrolysis system to produce wood oil and gas for consumption in the existing NSTL heating plants. The potential reduction in dependence on fossil fuels was to be an intermediate step in a long term NSTL plan of converting from fuel oil and natural gas to alternate energy sources. The overall result of this limited investigation indicated that the operation of a Tech-Air wood pyrolysis system at NSTL to produce wood oil and gas to supplement fossil fuels for consumption in the existing heating plants may be feasible (Reference 4). The specific conclusions of this preliminary study were as follows: a) Although the operation of production hardware has yet to be demonstrated, pyrolysis technology was well in hand; b) Products from pyrolysis of energy wood from one-half the NSTL acreage plus 67,500 (273 km^2) of the 120,000 buffer zone acreage (490 km^2) could supply 50% of the fossil fuel requirements; c) Combustion of wood oil and gas could be achieved in NSTL heating plants with little or no modifications; and d) Simple payback periods could range from 4.8 to 13 years depending on the factors considered.

The Mississippi Army Ammunition Plant (MSAAP) will be the first ammunition plant to be built by the Army in more than 25 years. The new plant will consist of three separate manufacturing complexes: The Projectile

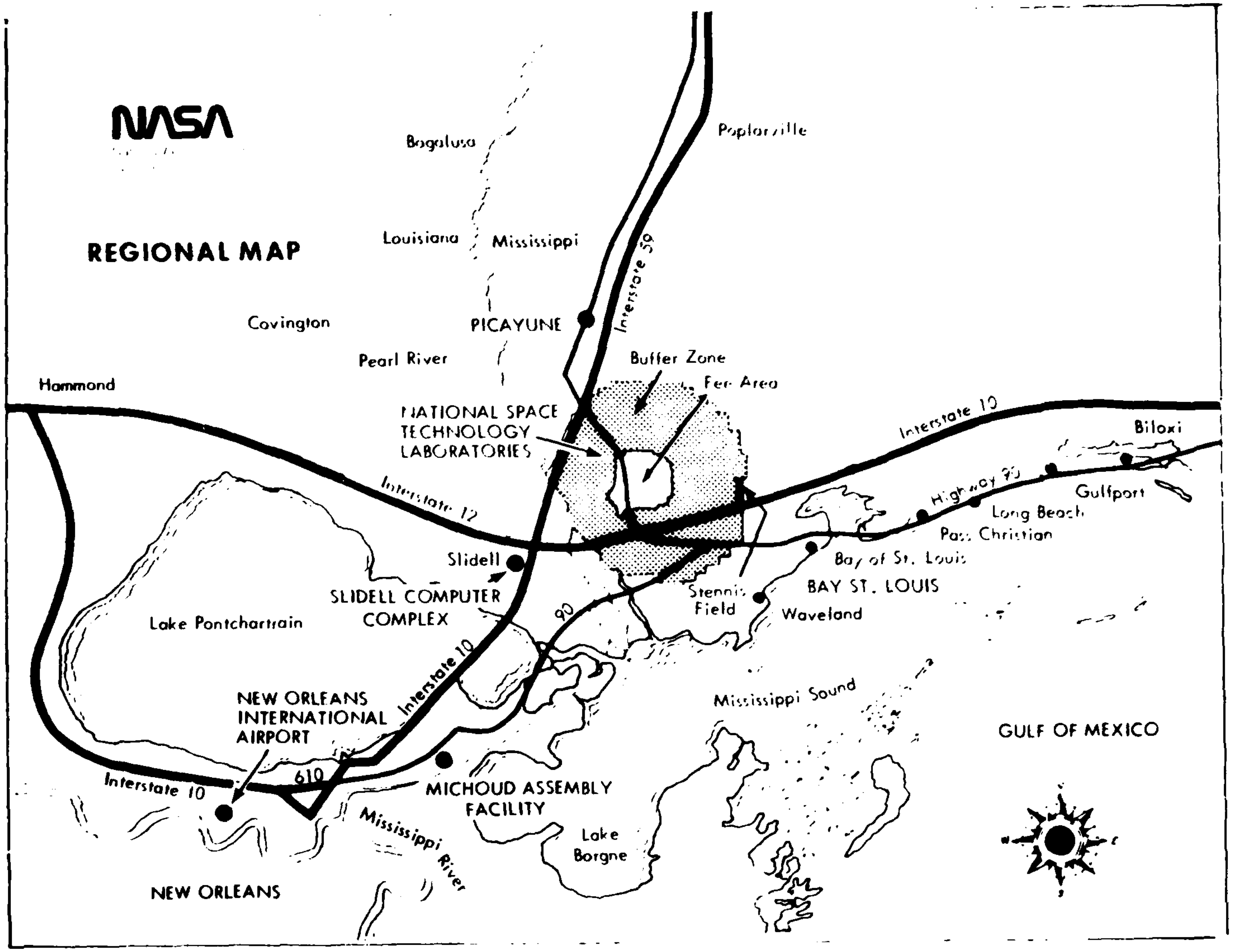

Figure 1. NSTL/MSAAP Regional Map

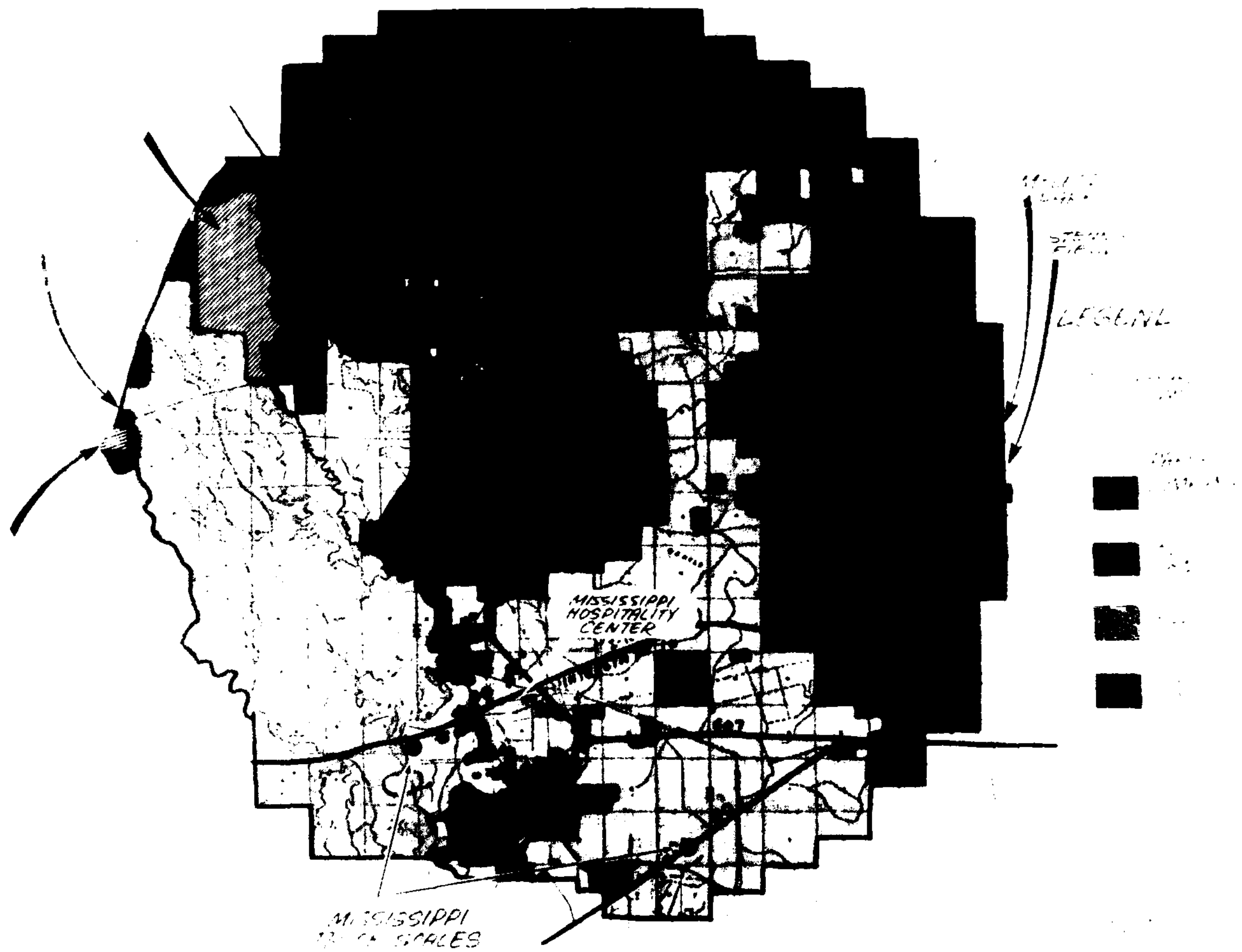

Figure 2. NSTL Land Ownership Map.

Metal Parts area, the Cargo Metal Parts area, and the Load, Assemble and Pack area, plus support and administrative facilities. Construction and equipping of this important new facility will take place over the next five years.

MSAAP is planning to use No. 2 fuel oil for the manufacturing operations and either diesel generators or coal fired boilers for the main power plant.

Current projections of total NSTL/MSAAP energy requirements are as follows:

NSTL/MSAAP Energy Requirements, 1983

Fuel Type	Average Monthly Usage	
Natural Gas	30,000 MCF	(849,600 m^3)
Electricity	3 to 4 $\bar{M}$ KWH	(10.8 to 24.4 TJ)
Oil (No. 2)	208,000 gal	(787 m^3)
Coal	830 tons	(756 x 10^3 kg)

Most experts agree that highly timbered areas in the South and West are examples of regions where energy wood utilization can have a tremendous impact on relieving the fossil fuel crisis. The purpose of this NASA/Army funded study is to ascertain whether NSTL/MSAAP is advantageously located to utilize wood energy.

The objective of this study is to evaluate the feasibility of utilizing a common energy wood (biomass) system to produce energy for use at NSTL and MSAAP. The approach to accomplishing this objective was to divide the study into two phases. The first phase was designed to provide a preliminary assessment of the application of direct combustion or pyrolysis of wood for the purpose of meeting all or some of the energy requirements of NSTL/MSAAP. In the second phase a detailed engineering analysis and economic evaluation was performed on plants for meeting the NSTL/MSAAP requirements. It was originally planned to use the economic evaluation to determine the cost of energy produced from a common NSTL/MSAAP energy wood plant. However, as the program proceeded, it became evident that the different forms of energy required at NSTL and MSAAP required individually designed systems. Therefore three different energy wood plants were evaluated: one which produced high temperature hot water (HTHW) for NSTL; a second plant for NSTL HTHW and co-generated electric power for the NSTL/MSAAP electric power grid; and a third design to produce steam for MSAAP.

The utilization of wood as a fuel source, particularly in the United States, is neither new nor unusual. The growth of the U.S. economy was related to the use of wood to fuel riverboats during the early development of the waterway systems. In 1850, 90% of all fuel consumed in the country was wood. It was used to heat most homes, power the railroads, converted to charcoal, and also to fuel half the iron production. It was not until 1880 that coal surpassed wood as a fuel. Table 1 presents the 100-year

Table 1. U.S. Energy Consumption Patterns, 1850-1974

Year	Coal	Petroleum	Natural Gas	Hydropower	Nuclear	Fuel Wood
			(Percent)			
1850	9.3	--	--	--	--	90.7
1860	16.4	.1	--	--	--	83.5
1870	26.5	.2	--	--	--	73.3
1880	41.1	1.9	--	--	--	57.0
1890	57.9	2.2	3.7	.3	--	35.9
1900	71.3	2.4	2.6	2.6	--	21.1
1910	76.8	6.1	3.3	3.2	--	10.6
1920	72.8	12.2	3.9	3.6	--	7.5
1930	58.7	23.2	8.5	3.4	--	6.2
1940	50.1	30.0	10.9	3.7	--	5.3
1950	36.7	38.4	17.5	4.1	--	3.3
1960	22.8	45.0	28.5	3.7	--	--
1970	19.2	43.9	32.7	3.9	.3	--
1971	18.2	44.2	32.9	4.1	.6	--
1972	17.3	45.8	32.0	4.1	.8	--
1973	17.8	46.5	30.5	4.0	1.2	--
1974	17.8	46.2	30.4	4.0	1.9	--

Source: U.S. Department of the Interior, Energy Perspectives, February 1975

trend of U.S. energy consumption of wood and the relationship of wood to the other types of energy sources (Reference 5). In addition, the growth of the national dependence on the less plentiful fossil resources is displayed with coal being supplemented by oil and gas during the last three decades.

Several factors contributed to this trend in the U.S. energy consumption pattern. Development of the coal industry in the Appalachians and the oil industry in the southwest provided the initial sources of cheaper, more convenient to use energy alternatives to wood. Later, regulation of natural gas prices provided the impetus for many industries to convert to this cheap, clean and efficient fuel. Still later, air quality regulations and the cost and inconvenience of operating complicated emission control equipment caused still more industries to switch from high sulfur coal to oil and natural gas.

By 1970, one of the major factors that contributed to the decline of wood as a fuel, economics, caused a renewed interest in this energy source. Overall, biomass supplied 1.5%, or slightly over one quad (10^{15} Btu or 10^{18} J) of the nation's energy in 1970, with most of the fuel going to the pulp and paper industry. In 1976 some 1.6 quads (1.6×10^{18} J) of energy were derived from silvicultural materials. By far, the largest amount was utilized in the pulp and paper industries, which consumed just under one quad from hogged fuel, sawdust, bark, and spent liquor. This amounted to 44.3% of the total energy consumed in that industry. During 1976, nonfossil organic fuels supplied approximately 30% of the total energy requirement for the sawmill industry, and 50% of the annual energy requirement of the plywood industry. Ferrosilicon producers, another significant consumer, use wood chips to add bulk to the electric furnace charge and, simultaneously, increase the electrical resistivity of that charge. Other substantial users of silvicultural materials as fuel include the wood furniture manufacturing industry, the University of Oregon, and the Eugene Water and Electric Board, which purchases and burns 240,000 tons (220×10^6 kg) of wood residue per year in a combination steam and electricity plant. AMTRAK, the National Railroad Passenger Corporation, consumes over a million pounds (400×10^3 kg) of sawdust logs and charcoal in its fleet of dining cars (Reference 5).

Another motivation for the resurgence of wood as fuel is related to the enactment of the Clean Air Act in 1967, amendments of 1977, and the relative high cost of other fuels. Wood is a much cleaner energy source than coal, the alternative solid fuel. Wood contains little or no sulfur and the combustion of fresh wood results in the generation of practically no pollutants except fly ash, but, aged wood can contain putrefaction agents and combustion processes utilizing aged wood may require pollution control equipment to reduce the content of these agents in process effluent streams. Wood trash from wood processing plants can contain toxic inorganics (Reference 6). Utilization of such wood trash in combustion processes may release these contaminants. In most areas, pollution control equipment will be required to reduce the content of such chemicals in the process waste streams. The solid residue from the combustion of wood is ash, which may have commercial value as fertilizer (Reference 7).

Many processing options can be applied to the conversion of biomass to energy. Some of these are summarized in Table 2. These processes range in their stage of development from laboratory scale to commercially proven processes. Most of the processes can be classified as either biological, combustion or thermo-chemical processes based on the definitions below:

1) Biological processes

   - Anaerobic digestion to produce methane

   - Hydrolysis of wood wastes to sugar with subsequent fermentation to ethanol

2) Combustion processes. These processes produce heat energy which is used to make steam. The steam is either used directly for heating purposes, or it is utilized in steam turbines to generate electricity.

Table 2. Summary of Nonfossil Carbon-To-Energy Processes and Primary Energy Products*

Conversion Process	Primary Energy Products	
		Thermal
Incineration	Energy	Steam
		Electric
Separation	Solid Fuels	Char
Pyrolysis		Combustibles
Hydrogenation		
Anaerobic Fermentation		Methane (SNG)
Aerobic Fermentation		Hydrogen
Biophotolysis	Synfuels	Low-Btu Gas
Partial Oxidation		Methanol
Steam Reforming		Ethanol
Chemical Hydrolysis		Hydrocarbons
Enzyme Hydrolysis		
Other Chemical Conversions		
	Energy-Intensive Products	Ammonia
		Other Chemicals

* Reference 5.

3) Thermo-chemical processes. These processes utilize heat or chemicals to break down solid wastes to gaseous or liquid fuels. The fuels are either burned on-site to produce heat for direct consumption or to generate steam for electricity generation, or they are stored for later use.

Anaerobic digestion involves the consumption of treated biomass to produce methane. As applied for removal of organics in waste treatment, the process takes place at low temperatures (up to 65°C) and requires a moisture content of 80% or more. Product gases consist mainly of methane and carbon dioxide. It is envisioned that these gases will be burned directly or upgraded to SNG by removing the carbon dioxide and impurities. Anaerobic digestion has only recently received attention for application to biomass other than animal manures.

The biological process most applicable to the conversion of wood waste is hydrolysis-fermentation. In this process, the cellulose is first hydrolyzed to glucose. The glucose is then fermented to ethanol. Such processes are being developed at several facilities (e.g., Gulf Oil and Black Clawson). However, these processes are not directly applicable to the requirements of the NSTL/MSAAP site and therefore were not considered as viable options in this study.

The two technologies basically considered for the NSTL/MSAAP application were direct combustion and thermochemical or, more commonly, pyrolysis. Industrially, the direct combustion of wood is practiced to generate steam at elevated pressures which is used to satisfy process demands and also to provide motive power for electric power generation. Wood combustion is proven technology. More than 200 wood burning boilers have been constructed in the United States during the last decade (Reference 5). Solid biomass materials like wood can be burned in refractory furnaces with fire tube boilers, waterwall boilers, vortex furnaces, and fluid-bed combustors. Fire tube boilers were used before the waterwall type, and they are still applicable for low solid biomass volumes. Refractory wall incinerators are suitable for low Btu content fuels, however, they usually require a large excess air supply.

Waterwall boilers require less excess air than refractory incinerators but require a higher heating value fuel. The walls are made of vertical tube panels. In these tubes the water is heated to generate saturated steam by radiative heat transfer from the flame. A convective heat transfer section is often added to superheat the steam, and also preheat the feed water and the air, thus increasing the overall efficiency of the boiler. The wood burning boilers are usually equipped with spreader stokers and moving grates, or the fuel may be pulverized and burned in suspension. Waterwall boilers are widely used at saw mills.

Fluidized bed combustors are very promising since they achieve excellent heat transfer and turbulence, and operate nearly isothermally. Pressurized air is blown through a distributor plate at the bottom of a vertical cylindrical reactor and fluidizes an inert medium such as sand. The solid fuel is fed near the bottom of the sand bed, and the fluidizing air provides the oxygen for combustion. A serious difficulty with fluidized beds is the carryover of fine particles with the exiting gases. This problem can be minimized by proper selection of operating parameters, and chamber design. Steam can be generated by placing heat exchanger tubes inside atmospheric pressure fluidized beds, or the fluidized bed can be operated at high pressure and the hot combustion gases expanded through a gas turbine. The latter scheme is not ready for commercial application due to the high degree of cleanliness required by gas turbines.

Vortex and centrifugal incinerators use centrifugal force to hold solids in place during combustion. Air is introduced tangentially into the furnace. These units are usually smaller than refractory furnaces or fluidized beds. However, they require a higher pressure air supply, and therefore may be more expensive to operate.

Pyrolysis of biomass can also be considered as emerging technology although not as proven and therefore not as reliable as direct combustion. All commercially available pyrolysis systems use vertical shaft reactors with combustion of the waste near the bottom of the reactor to provide the heat for pyrolysis. The syngas produced, which has a heat content of 95-350 Btu/scf (3-14 MJ/m^3) is either used on site to generate steam or electricity, or it is partially quenched to form a liquid fuel.

Frequently the solid wastes must be reduced in size and dried for efficient pyrolysis. Each pyrolysis system has a unique feed pretreatment system. Feed pretreatment units have been developed for the pyrolysis of Municipal Solid Waste (MSW), and modifications may be required for adapting to wood wastes. Gas cleanup systems to remove particulates from product gases are usually required. If an oil is produced, the quench water must also be treated to remove organic contaminants. The pyrolysis systems in the most advanced stage of development are discussed later (page 126).

TECHNICAL DISCUSSION

The feasibility of utilizing wood to produce energy for use at NASA's National Space Technology Laboratories and the proposed Mississippi Army Ammunition Plant depends on several factors. Foremost among these are the type and quantity of energy required at NSTL and MSAAP; the source of the available wood; the technology for converting the wood; the legal and environmental issues associated with the operation of an energy wood plant and the comparative economics of a wood system versus a fossil fuel system.

This study was designed to provide an evaluation of the factors which influence the feasibility of utilizing a common energy wood system at NSTL and MSAAP. During the course of the program, information was obtained from officials of both NASA and the U.S. Army, the Mississippi Forestry Commission, the U.S. Forest Service, Dr. R. L. Porterfield, Mississippi State University forestry consultant, and, from telephone surveys of wood products companies in the NSTL vicinity.

Energy Requirements

The current and future energy requirements at NSTL/MSAAP are projected to be supplied by the consumption of fossil fuels. In order to begin to examine the feasibility of utilizing energy wood as an alternative fuel source, the energy demand at NSTL and MSAAP must be established. It is equally important to determine the form of energy utilized (electric power, heat, steam, etc.) and the fluctuations in both the mixture and the amounts, the accepted tolerances in the energy supply and the expected growth in the energy demand. Although the objective of the study is to evaluate a common energy wood system for NSTL/MSAAP, an understanding of the energy requirements for each separate facility is important.

In 1978, NSTL consumed more than 1200 x 10^9 Btu (1.27 x 10^{15} J) of fuel for non-transportation energy uses in the form of natural gas, electric power and fuel oil. NSTL's annual consumption is projected to decline at about 100 x 10^9 Btu/year (106 x 10^{12} J) to a 1983 level of 725 x 10^9 Btu (766 x 10^{12} J) through strengthened conservation methods and the completion of the Space Shuttle program. The form in which the energy is required and the specific amounts are tabulated in Table 3.

Approximately 50% of the non-transportation fuel consumed at NSTL is natural gas which is fired in two high temperature hot water, HTHW, plants. HTHW is utilized to provide space heating and cooling. The Central Heating Plant (CHP) supplies hot water to the office buildings and laboratories. The Test Area Heating Plant, located approximately two miles from the CHP supplies HTHW to the test stands. A site map depicting the spacial relationship between the heating plants, test area, and office/laboratory area appears as Figure 3.

The CHP is a continuous, 24 hours a day, 7 days a week operation consisting of three high temperature hot water generators, each capable of producing 40,000,000 Btu/H (12 MW) under continuous loading and 50,000,000 Btu/H (15 MW) at peak load. Inlet water temperature to the generators is

Table 3. NSTL Energy Requirements

Year	Fuel Consumption Total		
	Electricity MW	Natural Gas $10^6 m^3$ (10^6 CF)	Fuel Oil m^3 (10^3 gallons)
1978	44,000	15 (541)	2,858 (755)
1979	46,600	14 (500)	2,524 (667)
1980	36,600	13 (463)	2,131 (563)
1981	34,400	13 (460)	651 (172)
1982	31,500	12 (418)	575 (152)
1983	30,000	11 (295)	575 (152)

from 250°F (121°C) to 340°F (171°C) and the outlet temperature is controlled at approximately 340°F (171°C). A description of the equipment and operation of the CHP is included in Appendix A.

The TAHP consists of three packaged HTHW generators. Each is rated for a continuous capacity of 15 x 10^6 Btu/h (4.4 MW). The hot water pressure is maintained at 425 psig (2.9 MPa) (maximum). The system is designed to supply 400°F (204°C) hot water with a 250°F (121°C) return water. A description of the TAHP system is also included in Appendix A.

NSTL utilizes fuel oil to fire four 1-1/2 MW, connected, diesel oil-fired electric power generators and ten diesel-driven water pumps. The electric power generators are used about six hours per day, one day a week to supply startup power for rocket engine testing. The pumps are used to circulate the large volumes of cooling water required for the rocket engine tests. The baseload NSTL electric power requirement is supplied by Mississippi Power Company at Gulfport, Mississippi to the NSTL substation.

The proposed MSAAP will consist of the facilities to manufacture, load and pack 155 mm shells. The plant is divided into three areas: Projectile Metal Parts, Cargo Metal Parts, Load Assemble and Pack and also the necessary support and administration facilities. The energy requirements for MSAAP are specified at two load levels. The peacetime level is an eight hour per day, five days per week operation. The mobilization (full production) is 24 hours per day, five days per week. MSAAP plans to utilize fuel oil, bituminous coal, and propane to supply their 416 x 10^6 Btu/h (122 MW) peacetime energy requirements. This includes 50% of the plant electric power, process heat, and 130 psig (1.0 MPa) process steam.

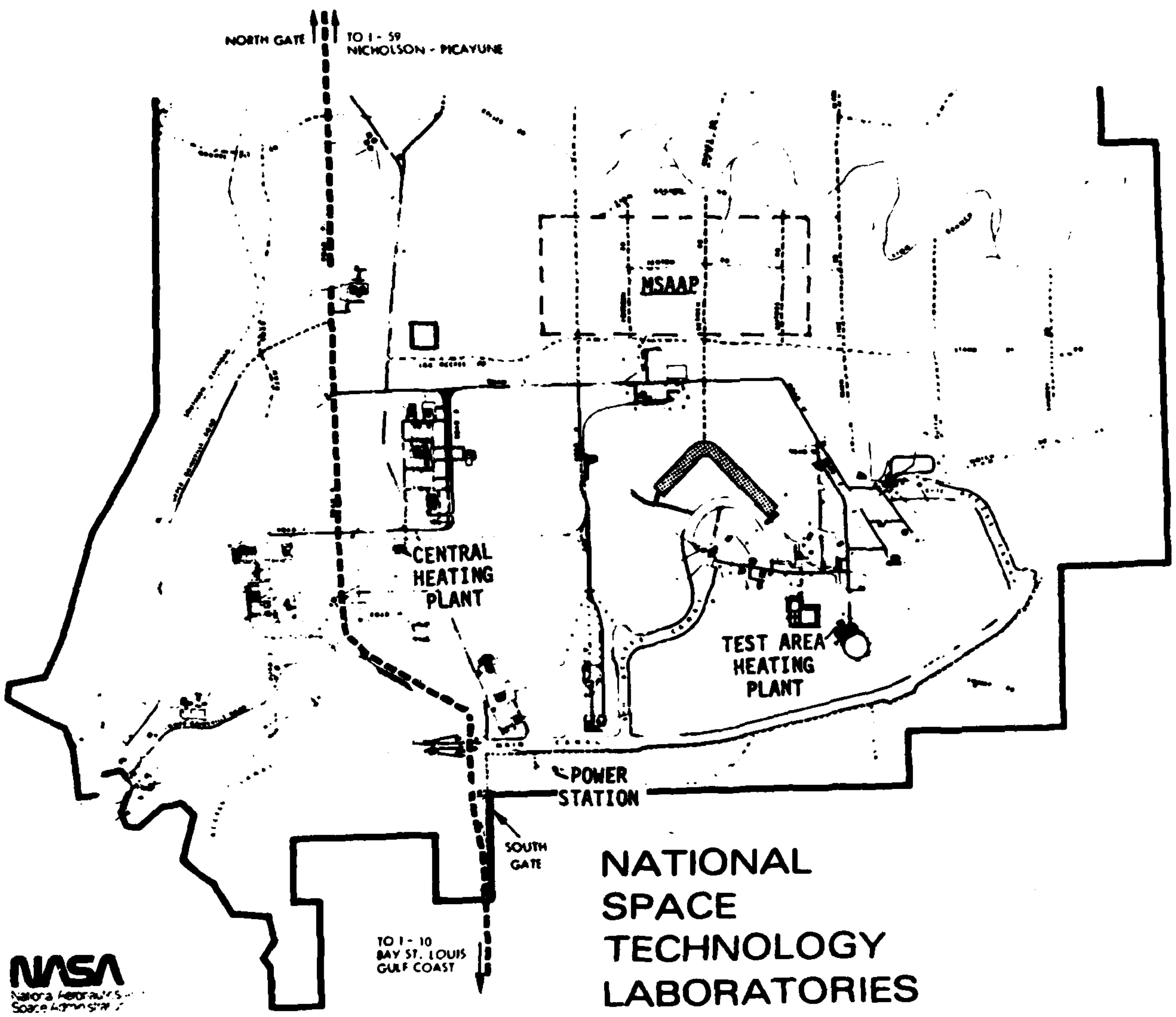

Figure 3. Site Diagram

There will be two parallel trains of fuel oil-fired furnaces in the Projectile Metal Parts area consisting of 10 furnaces each and ranging in fuel oil consumption from 0.7 to 7 x 10^6 Btu/h (0.2 to 2 MW). These furnaces are used to provide the heat required to form the body, base and ogive of 155 MM shells. There will be three explosive waste incinerators which will be fired with oil and a propane fueled contaminated waste incinerator in the load, assemble and pack area. The support facilities will consist of an electric power plant, a coal-fired steam boiler plant and a fuel oil-fired inert waste incinerator. The power plant facility will consist of four diesel engines with associated generating units and waste heat boilers. Each engine is 3000 KW with an approximate fuel rate of 1500 lb/h (0.086 kg/sec) of No. 2 fuel oil or 28 x 10^6 Btu/h (8.2 MW) heat input. There will also be four chain grate stoker-type coal-fired boilers designed to generate 32,000 lb/h (4 kg/sec) of 125 psia (0.96 MPa) steam, each. Each boiler is expected to have a fuel rate of 3,700 lb/h (0.4 kg/sec) of high-sulfur coal or 43 x 10^6 Btu/h (13 MW) heat input. MSAAP proposes to use electrostatic precipitators and a double alkali system to handle the flue gas particulates and sulfur emissions.

The planned fuel oil consumption by furnace type in each of the three areas and the support area of MSAAP is presented in Appendix B along with a description of the ammunition plant operation.

The objective of this study is to evaluate the feasibility of utilizing biomass to produce energy for use at NSTL and MSAAP. Given the highly probable situation that the amount of locally available energy wood could not support the combined 600 x 10^6 Btu/h (174.8 MW) fuel requirements of NSTL and MSAAP, it became necessary to set priorities for the form of fuel to be replaced. In the summer of 1978, the U.S. Government issued a statement prohibiting the use of natural gas fuel on government facilities after 1980. In response to this order, NSTL converted both the CHP and the TAHP to fire No. 2 fuel oil. The MSAAP had planned to utilize fuel oil, coal and electric power.

It was the decision of NASA and Army managers to prioritize the replacement of NSTL/MSAAP fuel consumption as follows:*

1. NSTL energy requirements being supplied by the consumption of natural gas.

2. MSAAP requirements planned to be supplied by the consumption of fuel oil.

3. MSAAP energy requirements planned to be supplied by the consumption of coal.

4. NSTL/MSAAP requirements for electric power.

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* This priority was established in the last quarter of CY 1978.

Summarized in Table 4 is the projected total fuel consumption for NSTL/MSAAP. The quantities are presented in the agreed upon order for replacement with energy from wood fuel. The actual replacement priority is contingent upon the type of wood to energy technology selected for NSTL/MSAAP. The two technologies which appear appropriate to meeting the needs of NSTL/MSAAP are pyrolysis and direct combustion. Either energy wood system will require equipment to procure, receive, store, convey, size, perhaps dry, and feed the solid wood fuel. Generally the only economically feasible energy wood handling procedure is to utilize a large centralized facility for most of the required solids handling. In a wood pyrolysis system, the wood handling system would be designed to supply wood to the pyrolysis unit. The wood oil, low Btu gas and charcoal produced would subsequently be supplied to the appropriate existing and planned fuel-oil and coal-fired furnaces as required. Therefore, the replacement priority presented is logical. In a direct combustion system, however, energy wood must be supplied directly to the wood furnace. Those energy demands for small amounts of individually controlled temperature exhaust gases, such as the 40 fuel oil furnaces in the MSAAP Projectile and Cargo areas, would require 40 separate wood feeding systems. The logistics of operating such a feeding system, even if automated, would make this fuel oil replacement, with wood, impractical. Therefore, for direct combustion type systems, the replacement priority would be adjusted toward replacement of large, centralized type furnaces. The first priority for fuel replacement would remain the natural gas/fuel oil NSTL, CHP and TAHP. However, the second priority would become the MSAAP coal-fired boiler.

Amount of Available Wood

The feasibility of utilizing wood to produce energy for use at NSTL/MSAAP depends on the quantity of wood that can be made available and the economic conditions of demand and supply. NSTL is located on 13,000 acres (52.6 km^2) of forest land surrounded by private forest which are heavily utilized by a thriving wood industry. The local wood industry includes logging, plywood and lumber, and paper manufacture. Therefore, the wood available to NSTL/MSAAP is in the form of mixed stands of pine and hardwood, wood residuals from sawmills, pole and paper operations, and uncollected waste from harvested lands such as the dead and cull trees.

The objective of this portion of the study was to determine the amount of wood in the government forest stands, residues from the local wood industries, and forest residues not utilized from harvesting operations in the area.

The fee area of the National Space Technology Laboratories lies entirely within the Costal Flatwood of the Gulf Coastal Plains. The northern portion of the buffer zone is in the extreme southern portion of the Lower Costal Plains. These lands are highly productive for wood fiber; most of the soils are expected to produce approximately two cords per acre per year of slash pine, or approximately 2.84 dry tons of biomass/ac/yr (63 kg/m^2/yr) in an unmanaged state. Intensive management practices such as bedding and fertilization on these soils have proven to appreciably increase yields. Volume figures reported for coastal Mississippi are

Table 4. NSTL/MSAAP Projected 1983 Fuel Consumption

Site	Fuel	Fuel Btu Content	Annual Fuel Consumption Amt/Year	Annual Fuel Consumption Btu/Hour	(GJ/H)
NASA	Natural Gas	1,000 $\frac{Btu}{scf}$	3.95×10^8 CF	71.45×10^6 [a]	(75.4)
		(37.29 MJ/m^3)	(11.2×10^6 m^3)	33.03×10^6 [b]	(34.9)
NASA	Electricity		3.0×10^7 KWH	1.08×10^8 [a]	(114.0)
NASA	Fuel Oil	138,000 $\frac{Btu}{gal}$	1.52×10^5 gal	6.72×10^7 [c]	(71.0)
		(38.50 GJ/m^3)	(0.58×10^3 m^3)		
Army (Projectile)	Fuel Oil	138,000 $\frac{Btu}{gal}$	4.79×10^5 gal	3.18×10^7 [d]	(33.6)
		(38.50 GJ/m^3)	(1.81×10^3 m^3)		
Army (Projectile)	Propane	2,550 $\frac{Btu}{scf}$	2.4×10^6 CF	3.06×10^6 [d]	(3.23)
		(95 MJ/m^3)	68×10^3 m^3		
Army (Cargo)	Fuel Oil	138,000	5.88×10^5 gal	3.9×10^7 [d]	(41.2)
		(38.5 GJ/m^3)	2.22×10^3 m^3		
Army (Cargo)	Propane	2,550 $\frac{Btu}{ft^3}$	1.65×10^6 CF	2.02×10^6 [d]	(2.13)
		(95 MJ/m^3)	46.7×10^3 m^3		
Army (Support)	Bit. Coal	11,500 $\frac{Btu}{lb}$	10,000 tons	80.4×10^6 [e]	(85.0)
		26.8 MJ/kg	21,172 metric tons		
Army (Support)	Fuel Oil	138,000 $\frac{Btu}{gal}$	1.273×10^6 gal	6.14×10^7 [e]	(64.8)
		38.5 GJ/m^3	4.818×10^3 m^3		
Army (Explosive Waste Incinerator)	Fuel Oil	138,000 $\frac{Btu}{gal}$	2,427 gal	1.29×10^6 [f]	(1.36)
		38.5 GJ/m^3	9.2 m^3		

[a] Based on 11-5 (11 h/day, 5 days/week) 2,750 H/yr

[b] Based on 13-5 6,010 H/yr

[c] Based on 6-1 312 H/yr

[d] Based on 8-5 2,080 H/yr

[e] Based on 11-5 2,860 H/yr

[f] Based on 5-1 260 H/yr

generally lower than expected due to the heavy timber losses sustained during Hurricane Camille in 1969 coupled with the heavy timber cutting which occurred just prior to the acquisition of the fee lands by the National Aeronautics and Space Administration.

The operable forest area in the fee area is 8935 acres (36 km^2). This excludes the 200 acre (0.8 km^2) Army test range, 150 acres (0.6 km^2) of marsh land in the southwestern portion of the fee area, and 630 acres (2.55 km^2) adjacent to and south of the test stands in the southeastern portion of the fee area. On the 8935 acres (36 km^2) of operable forest land, merchantable trees represent 52,000 tons (47 x 10^6 kg) of dry matter. These are trees at least 5.5 inches (0.14 m) in diameter at breast height (DBH) and of commercial value. Most commercial logging operations would remove trees this size or larger and then only as the merchantable bole and leave the remaining tops, branches and roots as residue. On the 8935 acres (36 km^2) of NSTL forest land, an additional 11,000 tons (10 x 10^6 kg) of wood biomass can be made available through a shear and whole-tree chipping operation. If a method to extract stumps and the main root system is utilized, an additional 9,000 dry tons (8 x 10^6 kg) can be added for a total of 72,226 tons (65 x 10^6 kg). Use of the proto-type biomass harvesting machine developed by Koch can add an additional 123,300 tons (11 x 10^6 kg).

Only 3390 of the 7500 acres (14 of 30 km^2) owned by NSTL in the buffer area is considered operable forest land. The area supports mainly loblolly pine. Merchantable timber represents 25,117 tons (23 x 10^6 kg) with top-wood adding 5,441 tons (5 x 10^6 kg) and the stump/root wood 4,419 tons (4 x 10^6 kg). Understory vegetation would add 47,129 tons (43 x 10^6 kg).

Therefore on the 12,330 acres (50 km^2) of operable forest land, a total of 277,632 tons (252 x 10^6 kg) of dry wood biomass is presently available. Based on actual stocking and estimated growth potentials, approximately 15,000 dry tons (14 x 10^6 kg) are being added annually. It is estimated that this is only half the potential which could be realized by good management. The estimated dry tonnages of wood biomass in the operable forest lands of the fee and buffer areas is tabulated by species group in Table 5. The method used to estimate the NSTL forest inventory is described in Appendix C.

Forest residues covers a variety of residues created by growing and harvesting commercial timber. Included are logging residues, trees removed in intermediate cuttings, trees and shrubs removed from the understory in even-aged stands, and the removal of trees killed by natural causes. Commercial logging operations are the most important source of forest residues. Logging residues are simply the leftovers of logging, the material which does not have enough economic value to justify the expense of removing it. Most logging operations remove only the "merchantable bole", the portion of the stem that is larger than some minimum diameter, usually 4 inches (0.1 m). Not removed during most conventional harvesting are the tops, branches and stump-root systems. The merchantable stem represents only about 55% to 70% of the total tree biomass; with the branches and stump-root comprising 18 to 20% each. Logging residues include tops,

Table 5. Survey of NSTL Forest Biomass Potential

	Merchantable	Tops	Roots/Stumps	Understory	Total
Fee Area					
Pine, tons	47,308	9,613	8,250		65,171
10^3 kg	42,917	8,720	7,484		59,121
Hardwood, tons	4,865	1,155	1,038		7,055
10^3 kg	4,413	1,048	939		6,400
Mixed, tons				123,300	123,300
10^3 kg				111,855	111,855
Subtotal, tons	52,173	10,768	9,285	123,300	195,526
10^3 kg	47,330	9,769	8,423	111,855	177,376
Buffer Area					
Pine, tons	20,038	4,117	3,474		27,629
10^3 kg	18,178	3,735	3,152		25,064
Hardwood, tons	5,079	1,324	945		7,348
10^3 kg	4,608	1,201	857		6,666
Mixed, tons				47,129	47,129
10^3 kg				42,754	42,754
Subtotal, tons	25,117	5,441	4,419	47,129	82,106
10^3 kg	22,786	4,936	4,009	42,754	74,485
Totals, tons	77,290	16,209	13,704	170,429	277,632
10^3 kg	70,116	14,704	12,432	154,619	251,862

Estimated growth = 2 cd/ac/yr x 12,332 ac = 35,023 tons/yr, dry
31,772 x 10^3 kg/yr, dry

branches, foliage, stumps and roots of trees of commercial value. In addition, they include trees of non-commercial species which are dead and standing or fallen trees of commercial species which are not economical to cut, portions of merchantable boles which are broken or shattered during tree felling operations, and finally, the understory brush which grows in the forest. Logging residues are available from the time the timber is harvested and ends when residues are decayed and incorporated into the soil. In the NSTL area, the material will only persist for a year or two, given the warm, humid climate and only the moderate resistance to decay for the local growing species.

Intermediate cuttings are sometimes made during the life of a commercial forest to remove trees of poorer quality or smaller size in order to increase the amount and value of the timber produced from the stand. There are several types of intermediate cuttings designed to alleviate specific types of problems. The most important of these are cleaning, liberation cutting, thinning and improvement cutting. However the only one which seems to have some promise as a source of residues for energy production is pre-commercial thinning which is the removal of trees which are not yet of merchantable size (Reference 6). It must be realized that intermediate cutting involves an investment whose return is not generally realized until the final timber harvest. However, if the thinnings are used for energy production, the commercial climate changes in the direction to make more of this material available for use.

Understory is the shade-tolerant vegetation that grows beneath the canopies of commercial forests and compete with the commercial species for soil nutrients. In the NSTL area, burning is the traditional method of understory removal. However, if some form of intermediate cutting is being practiced, it is conceivable that the understory will be removed at the same time and will then become available for energy use.

Forest survey growth figures for the 1967 to 1977 timeframe were used to estimate the amount of growing stock within a 50, 75, and 100 mile (80, 121, and 161 km) radius of NSTL. Since 100 miles (161 km) appears to be the economic limit for the transportation of saw timber, it was assumed it would also be the economic limit for the transportation of energy wood, a material with less than one-fifth the value of saw timber. Saw timber in the NSTL area is usually transported by truck although International Paper Company, the largest landholder in the area transports pulpwood by railroad. There is approximately 21 million cords of merchantable wood growing within a 50 mile (80 km) radius of NSTL. The estimated topwood and stump-root tonnage associated with this amount of growing stock is 3.2 million tons (3 M metric tons) of dry biomass. The corresponding values for the 75 and 100 mile (121 and 161 km) areas are presented in Table 6. Since only a portion of the growing stock is cut each year, the 1977 severance tax report was used to estimate the topwood and stump-root wood potentially available to NSTL from the lands harvested in 1977. As shown in Table 7, within a 50 mile (80 km) radius of NSTL there was available 177,100 tons (161×10^6 kg) of dry biomass in the form of logging residues exclusive of understory, non-merchantable timber, and foliage. The figures for the 75 and 100 mile (121 and 161 km) radii are 541,000 tons (491×10^6 kg) and 1,507,000 tons (1367×10^6 kg), respectively.

Table 6. Estimated Timber Supply 1977

		Growing Stock 10^6 Cords	Sawtimber 10^6 Cords	Topwood 10^6 Tons (10^9 kg)	Roots/Stumps 10^6 Tons (10^9 kg)
50 Mile (80 km) Radius					
Softwood	Miss	6.966	5.024		
	La.	2.191	1.607		
	Ala.	0	0		
	Total	9.157	6.631	5.80 (5.26)	4.01 (3.64)
Hardwood	Miss.	2.304	1.093		
	La.	1.392	0.611		
	Ala.	0	0		
	Total	3.696	1.704	1.70 (1.54)	1.49 (1.35)
75 Miles (121 km) Radius					
Softwood	Miss.	16.596	12.411		
	La.	14.294	11.140		
	Ala.	0	0		
	Total	30.890	23.551	16.49 (14.96)	13.79 (12.51)
Hardwood	Miss.	7.444	3.936		
	La.	8.196	3.629		
	Ala.	0	0		
	Total	15.640	7.565	8.16 (7.40)	7.20 (6.53)

(continued)

Table 6. (Continued)

100 Miles (161 km) Radius

		Growing Stock 10^6 Cords	Sawtimber 10^6 Cords	Topwood 10^6 Tons (10^9 kg)	Roots/Stumps 10^6 Tons (10^9 kg)
Softwood	Miss.	36.747	28.307		
	La.	15.443	12.011		
	Ala.	0.923	4.240		
	Total	53.113	44.558	34.68 (31.27)	24.58 (22.17)
Hardwood	Miss.	18.939	9.669		
	La.	9.992	4.504		
	Ala.	0.621	2.024		
	Total	29.552	16.197	14.02 (12.64)	9.41 (8.49)

% of Merchantable Volume

	Growing Stock Softwood	Growing Stock Hardwood	Sawtimber Softwood	Sawtimber Hardwood
Topwood	25%	23%	16.5%	27%
Roots/Stumps	20%	22%	15%	18%

billion bf/(90 cf/cd x 5 bf/cf) = million cds

dry wt/cd hdwd = 1.5 T (1.4 x 10^3 kg)

sftwd = 1.42 T (1.29 x 10^3 kg)

Table 7. Estimated Logging Residues From 1977 Cut

	Topwood		Roots/Stumps	
Counties in 50 Mile (80 km) Radius				
	10^3 tons	(10^6 kg)	10^3 tons	(10^6 kg)
Pine	72.0	(65.3)	59.4	(53.9)
Hardwood	25.5	(23.1)	20.2	(18.3)
Total	97.5	(88.4)	79.6	(72.2)
Counties in 75 Mile (121 km) Radius				
Pine	216.0	(196.0)	179.2	(162.6)
Hardwood	79.5	(72.1)	66.3	(60.1)
Total	295.5	(268.1)	245.4	(222.7)
Counties in 100 Mile (161 km) Radius				
Pine	606.4	(550.1)	505.5	(458.6)
Hardwood	212.7	(193.0)	182.8	(165.8)
Total	819.1	(743.1)	688.3	(624.4)

Forest inventory figures are obtainable from several sources, however, the principle one is the U.S. Department of Agriculture Forest Service.

Mill residues are the residues from the primary manufacture of logs into various products such as lumber and plywood. The residues are generated for two reasons: Logs are delivered to most primary manufacturing operations covered with bark which must generally be removed; and logs are usually in the shape of truncated cones that must be shaped into cylinders to be converted into the typical rectangular solid wood products. Logs are therefore debarked and sawed into shape producing bark, coarse residues, sawdust and planer shavings. Plywood production can produce bark, coarse residues in the form of veneer waste and core materials, sawdust, sander dust, and if cores are used for surfaced lumber production, even planer shavings.

In order to estimate the amount of mill residues potentially available to NSTL/MSAAP, TRW conducted a survey of 40 primary wood products companies within 150 miles (240 km) of NSTL/MSAAP. These companies were essentially asked how much residue they produced and what was currently being done with the material. If the material was being sold, who was the customer and what price was being paid? The companies were also asked if they would be willing to sell material to NSTL and what kind of contractual arrangements would they require from NSTL. A compilation of the information obtained through the TRW survey is presented in Table 8.

Another estimation of the amount of mill residue available in the NSTL area was made using 1977 Forest Survey figures for Mississippi and 1973 survey data for Louisiana. These results and the results of the TRW survey are compiled in Table 9.

While it can be concluded that substantial amounts of wood trash exist, there also exists a great demand for the material. Present users include paper and particle board manufacturers, nurseries and farms. A list of some potential competitors to NSTL for local wood residue is presented in Table 10. At paper and particle board companies, wood mill residues are not only used as raw materials but also as boiler fuel. Based on the survey data, wood chips in the NSTL area are sold for \$13 to \$16 per wet ton (\$14 to \$18 per 10^3 kg wet), bark for \$6 to \$7 per wet ton (\$7 to \$8 per wet 10^3 kg), and planer shavings for \$11 to \$12 per ton (\$12 to \$13 per 10^3 kg). A tabulation of physical properties of mill residues is presented in Table 11.

Having established the amount of wood in existence in the proximity of NSTL, it is necessary to relate the energy value of the wood to the energy requirements of NSTL/MSAAP. The heating value of wood depends on the species. Table 12 shows the heating values of representative North American commercial species (Reference 8). As shown, the heating values of these species range from 7900 to 9700 Btu per pound (18.4 to 22.5 MJ/kg) with southern pine having a value of 8600 Btu per pound (20 MJ/kg). The heating value of the hardwood species tends to be lower and was assumed to be 7820 Btu per pound (18.2 MJ/kg). The heating values of different wood species, on a moisture-and-resin-free basis are about the same at 8280 Btu per pound (19.2 MJ/kg). Resin has a much higher heating

Table 8. TRW Survey of the Potential Mill Residue Resource

SUPPLIER	RESOURCE	WOOD CHIPS	PLANER SHAVINGS	BARK	SAWDUST
0 to 50 Miles (0 to 80 km) From NSTL/MSAAP					
Arnold B. Smith	tons/day	Ø	Ø	10 to 15	Ø
Timber Company, MS	metric tons/day	Ø	Ø	9 to 14	Ø
Contractual Req:	$/ton ($/10^3 kg) wet[a]	-	-	-	-
$6 to $8 per ton plus	current buyer	-	-	Nurseries	-
Negotiated freight costs					
50 to 75 Miles (80 to 121 km)					
J.M. Rodgers & Sons, MS	tons/day	35	23.5	Incl. with Planer Shavings	
Contractual Req:	metric tons/day	32	21.3		
NSTL guarantee to buy	$/ton (10^3 kg) wet	$15.61 (17.20)	5.70 to 6.50		
mill residue at all	current buyer	Int. Paper Co.	(6.28 to 7.16)		
times			Int. Paper Co.		
			Scott Paper Co.		
			Klines Eibbet		
Cumbest Manufacturing	tons/day	40		12	Incl. with
Company, MS	metric tons/day	36	Ø	11	bark
Contractual Req.	$/ton ($/10^3 kg) wet	16.30 (17.97)			
NSTL must pay cost of	current buyer	Int. Paper Co.		Int. Paper Co.	
transportation plus					
incentive to replace					
Int. Paper Co.					
Purvis Hardwood Lumber	tons/day	68		Incl. with Shavings	
Company, MS	metric tons/day	62			
Cont. Req: will sell if	$/ton ($/10^3 kg) wet[b]	16.00 (17.64)	1/truckload		
NSTL provides	current buyer	Crown Zellerback	Local Farms	Stockpiled	
transportation					

[a] Because of the nature of the material planer shaving prices are per dry quantity

[b] FOB Mill

[c] Includes 8 miles (12.9 km) freight

Table 8. (Continued)

50 to 75 Miles (80 to 121 km) cont'd.

SUPPLIER	RESOURCES	WOODCHIPS	PLANER SHAVINGS	BARK	SAWDUST
Jack Forbes Lumber Co. MS	tons/day	40	13	13	13
Cont. Req: NSTL price	metric tons/day	36	12	12	12
must be higher than	$/ton ($/10³ kg) wet[b,c]	15.60 (17.20)	5.04 (5.56)	5.04 (5.56)	5.04 (5.56)
current buyers	Current buyer				
Tristate Pole and Piling, MS	tons/day	Firewood	30	Incl. with	0
Cont. Req: specified	metric tons/day	-	27	Shavings	-
quantity and 3 to 6	$/ton ($/10³ kg) wet	-	$6.85 (7.55)	-	-
months advance notice of	Current buyer	-	Int. Paper Co.	-	-
shut-off					
Batson Lumber Co., LA	tons/day	80	36	Used to fuel boilers	
Cont. Req: open for	metric ton/day	73	33		
negotiations	$/ton ($/10³ kg) wet	15 to 16 (17 to 18)	12 (13)		
	Current buyer	Paper Company			
Clemons Brothers Lumber					
Co. LA					
Cont. Req: will negotiate	tons/day	125	25	Used to fuel boilers	
to sell residue in excess	metric tons/day	113	23		
of that committed to	$/ton ($/10³ kg) wet	-	-		
current customer	Current buyer	Crown Zellerback	Georgia Pacific		

75 to 100 Miles (121 to 161 km) from NSTL/MSAAP

SUPPLIER	RESOURCES	WOODCHIPS	PLANER SHAVINGS	BARK	SAWDUST
Rodgers Lumber Co. MS	tons/day	100	15	50	Incl. with bark
Cont. Req: Right Price	metric tons/day	91	14	45	
	$/ton ($/10³ kg) wet	25 (28)	15 (17)	10 (11)	
	Current buyer	Various paper companies	Poultry Farms	Various	
Masonite Corp., MS	tons/day	400	50	110	100
Cont. Req: Willing to	metric tons/day	363	45	100	91
sell to NSTL	$/ton ($/10³ kg) wet	28 (31)	10 (11)	4 (4)	4 (4)
	Current buyer				

Table 8. (Continued)

75 to 100 Miles (121 to 161 km) cont'd.

SUPPLIER	RESOURCE	WOOD CHIPS	PLANER SHAVINGS	BARK	SAWDUST
Daughty Lumber Co.,LA	tons/day	60 to 70	Ø	40	Incl. with bark
Cont. Req.: Price	metric tons/day	54 to 64	-	36	-
comparable with present	$/ton ($/10^3 kg) wet	11 (12)	-	-	-
contracts	Current buyer	Crown Zellerback			
		Georgia Pacific			
		100 to 150 Miles (161 to 240 km) from NSTL/MSAAP			
Edward Hines Lumber Co.MS	tons/day	123 to 133	23 to 30	Used to fuel boilers	
Cont. Req.: Right price,	metric tons/day	112 to 121	21 to 27	-	
FOB Mill.	$/tons($/10^3 kg) wet	13 to 14.50 (14 to 15.98)	11.65 (12.84)		
	Current buyer	Int. Paper Co.(@2000 T/mo)	Georgia Pacific Co.		
		Arkansas Kraft			
		Scott Paper Company			
Franklin Lumber Co., MS	tons/day	22 to 24	Ø	10	Incl. with bark
Cont. Req.: No stringent	metric tons/day	20 to 22	-	9	
specifications on bark	$/ton ($/10^3 kg) wet	-	-	-	
	Current buyer	Crown Zellerback		Stockpiled	
		St. Regis			
Georgia Pacific Stud Mills, MS.		Currently purchasing chips, bark and sawdust from mills within 150 miles at an average price of $30/ton ($33/metric ton), dry, delivered.			
Koppers Company, Inc. MS	tons/day	24	20	Used to fuel boilers	
Cont. Req.: Right Price	metric tons/day	22	18		
	$/ton ($/10^3 kg) wet[b]	10 to 12 (11 to 13)	4.20 (4.63)		
	Current buyer	St. Regis	Mills & Paper Companies		
		Crown Zellerback			

Table 8. (Continued)

100 to 150 Miles (161 to 240 km) cont'd.

SUPPLIER	RESOURCE	WOOD CHIPS	PLANER SHAVINGS	BARK	SAWDUST
Leaf River Forest Product, MS	tons/day	800	80	200	120
Cont. Req.: A 1 to 3 year contract to buy all available mill residue, Advanced notification of cut-off with another buyer provided; and regular haul-out of mill residue	metric tons/day	726	73	181	109
	\$/ton (\$/10^3 kg) wet	14.14 (15.59)	8.50 (9.37)		2 (2)
	Current buyer	International Gypsum & St. Regis	MacMillan Bloedel	Used to fuel boilers	St. Regis
St. Regis Paper Co., MS	tons/day				
	metric tons/day				
	\$/ton (\$/10^3 kg) wet[b]	16 (18)		12 (13)	
	Current buyer	St. Regis uses 45 tons/day (41 metric tons/day) of chips, bark and sawdust.			
Olson Lumber Co., LA	tons/day	1000	Used to fuel boilers		
Cont. req.: Willing to negotiate with NSTL at the end of 5 to 7 year contract with International Paper Co.	metric tons/day	900			
	\$/ton (\$/10^3 kg) wet	14.50 (15.98)			
	Current buyer	Paper Companies and Particle Board Companies			

Table 9. Reported Unused Mill Residues; 1977 Figures for Mississippi; 1973 Data for Louisiana

Type of Residue	10^3 Tons (10^6 kg), Dry Weight		Aug., Sept. 1978 TRW Survey 10^3 Tons (10^6 kg), Dry Weight	
	50 Mile (80 km) Radius			
Bark	16.7	(15.2)	2	(2)
Coarse Residue	8.	(7)	0	
Fine Residue	12.	(11)	0	
Total	16.7	(15.2)	2	(2)
	75 Mile (121 km) Radius			
Bark	55.1	(50.0)	2	(2)
Coarse Residue	0.6	(0.5)	81	(74)
Fine Residue	10.		3	(3)
Total	55.7	(50.5)	86	(79)
	100 Mile (161 km) Radius			
Bark	79.8	(72.4)	27	(24)
Coarse Residue	1.1	(1.0)	87	(79)
Fine Residue	0.2	(0.2)	14	(13)
Total	81.1	(73.6)	128	(116)
	150 Mile (240 km) Radius			
Bark			27	(24)
Coarse Residue			280	(254)
Total			307	(278)

Table 10. Major Competitors for Local Mill Residues

Paper Companies	
	Crown Zellerbach
	International Paper Company
	Scott Paper Company
	St. Regis Paper Company
	MacMillan Bloedel
	Klines Eibbet
Particle Board Manufacturers	
	U.S. Plywood
	Georgia Pacific Corporation
	Masonite Corporation
	International Gypsum
Others	
	Nurseries
	Firewood Suppliers
	Farms

value than wood itself, about 17,000 Btu per pound (39.5 MJ/kg). Thus woods such as pine, which contain resin, have higher heating values than resin-free woods such as the true firs and most hardwoods. The understory tonnages reported in Table 5 were based on a 3:1:1 soft-hardwood, hard-hardwood, pine mixture. The heating value for this mixture was assumed to be 7980 Btu per pound (18.5 MJ/kg).

Utilizing the heating values to convert the tons of wood existing in the NSTL forest stand, residues from harvesting operations, and mill residues; the energy available to NSTL/MSAAP in the form of biomass is over 33×10^{12} Btu (3.48×10^{16} J). These values are shown in Table 13.

The predicted 1983 annual consumption of energy at NSTL/MSAAP by fuel type is presented in Table 14. As shown, the total annual fuel consumption at NSTL/MSAAP is predicted to be 1.3×10^{12} Btu (1.4×10^{15} J). It is apparent that NSTL energy requirements can be met by converting the existing biomass to energy. The current growth potential of the NSTL forest alone would supply approximately 33% of the energy requirements, assuming the potential biomass energy is equivalent to the currently consumed fossil fuel energy. Retaining the assumption of energy equivalence, it appears that 33% of the NSTL forest inventory could be harvested

Table 11. Characteristics of Available Mill Residues

Wood Trash	Particle Size[a]		Bulk Density[a] Wet		Tons Per Day		Cost	
	inches	(meters)	lb/ft^3	(kg/m^3)	Wet TPD	$(10^3$ kg)	Wet $/Ton	$(10^3$ kg)
Bark	3	(0.076)	25	400	530[b]	480	4-10	4-11
Sawdust	1/6	(0.004)	15	240	110	100	2- 5	2- 6
Wood Chips	1-7/8	(0.048)	30	480	2800	2540	13-28	14-31
Planer Shavings	1	(0.02)	10	160	330	300	4-15	4-17

[a] Bulk density and particle size supplied by Masonite Corp. of Hattiesburg, Mississippi.

[b] Figure includes sawdust.

Table 12. Heating Values of Various North American Woods

Species	Heating Value Oven-dry Btu/lb	Oven-dry MJ/kg
Douglas Fir	8,890	20.66
Western hemlock	8,410	19.55
White fir	8,210	19.08
Western red cedar	9,700	22.55
Southern pine	8,600	19.99
Ponderosa pine	9,110	21.18
Black cottonwood	8,800	20.46
Red alder	7,990	18.57
Beech	8,150	18.94
Elm	8,170	18.99
Hickory	8,050	18.71
Red maple	7,990	18.57
Red oak	8,050	18.71
White oak	8,150	18.94
Sycamore	7,990	18.57

Sources: Smith, 1974; Howard, 1973; Mason, 1975; Forest Products Research Society

Table 13. Potentially Available Energy Wood

FEE AREA STANDS, TOTALS

(MERCHANTABLE, TOPS, ROOTS/STUMPS AND UNDERSTORY)

PINE	1.12×10^{12} Btu	1.18×10^{15} J
HARDWOOD	0.11×10^{12}	0.12×10^{15}
UNDERGROWTH	1.97×10^{12}	2.08×10^{15}
	3.20×10^{12} Btu or 358×10^{6} Btu/Acre for 8932 Acres	3.38×10^{15} J or 93.5 TJ/km^2

BUFFER ZONE STANDS, TOTALS

(MERCHANTABLE, TOPS, ROOTS/STUMPS AND UNDERSTORY)

PINE	0.48×10^{12}	0.51×10^{15} J
HARDWOOD	0.12×10^{12}	0.13×10^{15}
UNDERGROWTH	0.75×10^{12}	0.79×10^{15}
	1.34×10^{12} Btu/Acre or 395 x 106 Btu/Acre for 3390 Acres	1.43×10^{15} J or 104 TJ/km^2

UNMANAGED GROWTH POTENTIAL = 2 CD/AC/YR or 0.57×10^{12} Btu/Yr (0.6×10^{15} J/Yr)

LOGGING RESIDUES, ANNUALLY

(EXCLUSIVE OF UNDERSTORY, NON-MERCHANTABLE TIMBER AND FOLIAGE)

50 MILE RADIUS	PINE	2.25×10^{12} Btu	2.38×10^{15} J
	HARDWOOD	0.71×10^{12} Btu	0.75×10^{15} J
75 MILE RADIUS	PINE	6.8×10^{12} Btu	7.2×10^{15} J
	HARDWOOD	2.28×10^{12} Btu	2.41×10^{15} J
100 MILE RADIUS	PINE	19.12×10^{12} Btu	20.19×10^{15} J
	HARDWOOD	6.18×10^{12} Btu	6.53×10^{15} J

MILL RESIDUES, ANNUALLY

50 MILE RADIUS	0.15×10^{12} Btu	0.16×10^{15} J
75 MILE RADIUS	1.13×10^{12} Btu	1.19×10^{15} J
100 MILE RADIUS	1.67×10^{12} Btu	1.76×10^{15} J

Table 14. Summary NSTL/MSAAP Fuel Requirements For 1983

Fuel Type	Btu/Yr	J/Yr
NASA Natural Gas Requirement	0.395×10^{12}	0.417×10^{15}
Army Fuel Oil for Heat Treat Furnaces	0.150×10^{12}	0.155×10^{15}
NASA Fuel Oil for Electric Power	0.021×10^{12}	0.022×10^{15}
Army Fuel Oil for Electric Power	0.176×10^{12}	0.186×10^{16}
Army Coal	0.230×10^{12}	0.243×10^{15}
NASA Electric Power Consumption at 33% Efficiency	0.309×10^{12}	0.326×10^{15}

to supply the 1983 NSTL/MSAAP fuel requirements. However, it requires many years to replace a forest resource. Most forestry experts recommend at least 20 to 25 years for rotation (Reference 9). Therefore, the NSTL forest could initially only support a small portion of the energy requirements. Most of the required biomass would have to come from harvest and mill residues procured from the surrounding area. There exists extreme competition for this material and all wood in this area of Mississippi. Saw timber sells for $185 per 1000 board feet in southern Mississippi as compared to $75 per 1000 board feet only 75 miles (121 km) to the north. This price difference not only reflects the competition for the resource in southern Mississippi but also that the forests in this area are being managed (Reference 10).

Prior to addressing the supply of biomass to an energy plant, the amount of biomass energy actually required to replace fossil fuel energy will be discussed. The equivalence of biomass energy to fossil fuel energy depends on the final form of the energy produced from the fuel (i.e., heat, electric power, steam) and on the method utilized to effect the conversion. The methods which are applicable for converting energy wood to the forms of energy currently used at NSTL/MSAAP are discussed in the following sections of this report.

Commercially Available Wood To Energy Conversion Technology

There are several processing options which may be applied to the conversion of biomass to energy. These processes range in stages of development from laboratory scale to commercially proven. Of all of these processes, only those which fall into the catagories of direct combustion or pyrolysis can be considered as advanced enough to be applicable to the requirements of NSTL/MSAAP.

Fundamentally the combustion of wood fuels is no different from the combustion of other fuels. Air is required, which combines with the applicable constituents of the fuel to produce products of combustion. The inerts are left, some of which go off with the products of combustion and some of which remain in the bottom ash. Wood has a complex chemical composition. Its basic constituents (90 to 95%) are cellulose, hemicellulose and lignin. Smaller quantities (5 to 10%) of extraneous materials such as volatile oils, resin and fatty acids, native pigments, tannides, organic nitrogenous compounds, inorganics, and tar-like substances are also present. Wood also contains a certain amount of moisture. Lumber mill waste may be 40 to 65% water depending upon the nature of the operation. Southern paper mill bark averages 50%. Although wood composition may vary from one species to another and even within species, on the average, absolutely dry wood of any species contains about 49.5% carbon, 6.3% hydrogen, and 44.2% oxygen (Reference 11).

On heating, wood undergoes a number of physical and chemical changes. Initially, wood looses weight due to the escape of water vapor and various other volatile components. Moisture in the wood has two principal effects. Steam produced during the heating operation distills the various extraneous materials at temperatures below their normal boiling points, and the available heating value of the wood as a fuel is reduced, since heat is

used to evaporate moisture. Experts recommend that wood having moisture contents between 65 and 70% on the as-fired basis is uneconomical to burn alone (Reference 12). The thermal decomposition of wood begins at just above 212°F (100°C) but proceeds very slowly. Above 392°F (200°C) there is considerable decomposition and above 518°F (270°C) the process becomes exothermic. Hemicellulose, followed by cellulose and then lignin decomposes and the wood undergoes the breakdown to carbon and a wider number of simple hydrocarbons which are then converted to carbon dioxide and water vapor as combustion continues.

Combustion is typically accomplished with excess air. That is, the amount of air supplied with the fuel is in excess of the amount stoichiometrically required to convert the carbon and hydrogen in the fuel to carbon dioxide and water vapor. There exist several industrial methods for combining air and energy wood in a combustive environment. These include pile burning, inclined grates, spreader stoker fired onto grates, cyclone furnaces, suspension type furnaces and fluid-bed combustion. In all except fluid-bed combustion, heat is removed by radiant heat transfer to the heat receiving surfaces. Fluid-bed combustion involves the production of heated gases from wood combustion and then leading these gases to banks of tubular heat absorbing surfaces for recovery of the heat energy primarily by convection.

Pile burning consists of dumping fuel through a spout or a series of spouts into one or more cells or furnaces, where it remains in a conical pile and dries due to the heat of the furnace, and is burned around the periphery and on the face of the cone. While air is admitted through the grates, most of the air for combustion is admitted through layers or banks of tuyeres located in the sidewalls. Such furnaces are usually refractory construction although recent designs have incorporated water cooling in the upper walls and the roof to reduce maintenance. A large pile of fuel in the furnace means that there is no direct relationship between the rate of input and the rate of steam output; such control must be achieved by varying air flow. Pile burning has the advantage that most of the fuel is burned in a quiescent state and carry-over is minimum. Little attention to the fuel feed is required, however steam pressure may be quite erratic if wood is the only fuel being burned. Maintenance is fairly high because of the large areas of refractory involved in immediate proximity to the burning fuel. This is the oldest type of wood burning furnace and many small installations throughout the country are still successfully in operation.

Inclined grate firing is partway between pile burning and stoker firing. Many installations have been made employing an upper refractory hearth section for drying and lower cast iron grate sections for air admission, terminating in a cast iron ash section. The grates may be water cooled, the cooling water being tied to the main boiler circuit, so that no heat is lost on this account. The fuel enters in a ribbon, passes over the drying section where some increase in thickness of the fuel bed occurs, and subsequently, the ashes flow by gravity to the horizontal ash section at the bottom. In modern designs, the furnace is built in one continuous grate with a series of spouts at the top and a series of ash removal doors at the rear and bottom. Air admission under the grate is

divided into a series of zones across the width of the grate as well as an upper and lower zone in the other direction. As with pile burning, this system of burning does not require accurate control of the incoming fuel. Steam output may be varied by changes in the air flow. Since fuel size is not of significant importance and wet fuel can be adequately dried as it moves down the grate, this type of firing has many applications to wood residue materials.

In spreader stoker firing onto grates, fuel must be delivered to the stoker at a controlled rate since no storage can be provided. The fuel is delivered by the stoker into the furnace where some of it burns in suspension and the rest lands on a grate. Some installations are constructed with the stoker high above the grate which permits more drying in the furnace before the fuel lands on the grate with a larger portion of the fuel being burned in suspension, and probably greater carryover of fly ash and char out of the furnace. Other installation have the stokers set only high enough above the grate to achieve good distribution. However, carryover is higher with this type of firing than with either pile burning or inclined grates. There are basically two types of stokers, the mechanical type in which mechanical means, using paddles, throw the fuel into the furnace, and the pneumatic type. The mechanical spreader stoker can only be used satisfactorily with suitably hogged and sized material, free from long stringy pieces. The pneumatic type of stoker uses high pressure air to inject the fuel into the furnace. Little or no attention is required to fuel sizing and pieces up to four feet (1.2 m) by six inches (0.15 m) diameter have been fed successfully. With spreader stoker firing onto grates, fuel moisture content is limited to 55%. Higher moisture contents require the addition of refractory or the use of supplementary fuel. The firing rate is controlled by regulating the rate of air and fuel supply to the furnace.

Three types of grates are commonly used: stationary grates, dump grate, and traveling grate. The stationary grate is equipped with water tubes tied into the steam generator circuit. This allows air preheat temperatures to rise to 550°F (288°C) without damaging the grate. Stationary grates need not be horizontal. They may be inclined so that the fuel slides to the ash discharge point by gravity. The dump grate has the advantage of being more easily cleaned than the stationary grate, but it is limited to an air preheat temperature of around 400°F (204°C) when firing 50% moisture fuel. The traveling grate is perhaps the most popular and has a number of advantages in comparison with the others. The continuous dumping of ash by traveling grates provides more effective ash cleaning and therefore a longer grate life.

The cyclone furnace has long been recognized as a method of firing coal. It is claimed that this method recovers 40% of the heat input from the bark and has low fly ash carryover in relation to some of the other firing methods.

The newest innovation in wood burning is suspension firing. It is analogous to pulverized coal firing. Wood-waste or bark is hogged to small size and dried so that it burns in suspension. There are no moving parts in the furnace; hence, maintenance can be performed without a boiler

outage. In most installations, a small grate is provided at the bottom of the furnace to burn the large fuel particles which would otherwise fall into the ash hopper and increase the unburned combustible loss. Fuel is usually blown into the furnace with hot or cold air. With hot air, the feed is conditioned for burning before entering the furnace. Combustion Engineering's hot-air system requires approximately three kilograms of air per kilogram of bark for drying the bark. The Combustion Engineering's cold air system needs 0.5 kilograms of air per kilogram of bark for conveying. The larger air volume, higher temperature, and complicated air flow and controls make these furnaces more expensive than the more conventional ones described.

"Fluid-bed burners are generally used for the combustion of problem fuels or for combustion of fuels which are to be burned with an additive. Problem fuels are typically characterized by high moisture levels, slow burning rates (such as char), large material size or high inert levels. Some wood waste material may contain moisture contents up to 65%, be variable in size, and contain considerable amounts of noncombustibles (earth and stone) that may be gathered along with the waste wood in the yard. In addition, carbon-containing fly ash from conventional stoker-fired wood boilers may be utilized. Although fluid-bed burners can operate on standard fuels, such applications are generally not practical due to the high fan horsepower associated with a fluid-bed system along with the higher capital cost in comparison to standard burners" (Reference 13). Fluid-beds operate in a stable manner only when the solid particles are carefully sized and gas velocities controlled within a narrow range. To provide such conditions for feeding irregularly and erratically shaped wood waste and inert materials of unpredictable character, the fluid-bed is established and maintained with prepared material such as sand and the waste fuel fed at a slow uniform rate. The combustion air is the fluidizing medium. Excess air and moisture content are regulated so that the bed temperatures are considerably below the melting or fusion point of the bed material, and generally range between 1200 and 1800°F (649 to 982°C). Fluid-bed combustors greatly increase the combustion efficiency of solid fuels; 95 to 99% as compared to 80% for stokers. The rate of pyrolysis of the solid material is increased by direct contact with the hot inert bed material. The charred surface of the burning solid material is continuously abraded by the bed material, enhancing the rate of new char formation and the rate of char oxidation. Gases in the bed are continuously mixed by the bed material, thus improving the flow of gases to and from the burning solid surface and enhancing the completeness and rate of gas-phase combustion reactions. However, because of the loss of the radiant section of the furnace, the overall boiler efficiency for fluid-bed burners is approximately 30% below the other types of furnaces discussed (Reference 14).

There are several equipment manufacturers and engineering firms that supply each type of furnace discussed in this section. Some of the companies contacted during the course of this study are listed by furnace type below:

Pile burners: Agnew Environmental Products
Wellons, Inc.

Stokers:	Alpha Consolidated Industries, (CONAL)
	Babcock & Wilcox
	Bumstead-Woolford
	Combustion Engineering
	Detroit Stoker
	Foster Wheeler Energy Corp
	International Boiler Works
	Peabody Engineering Co.
	Riley Stoker Corp
	The McBurney Corp
	Zurn
Suspension Firing:	Coen Company
	Energex Limited
Fluid Bed:	Combustion Power Co., Inc.
	Dorr-Oliver Inc
	FluiDyne Engineering Corp
	Johnson Boiler Co
	Thermal Processes Inc
	York-Shipley

Five of the more familiar biomass direct combustion processes are described in Appendix D along with operational histories, plant economics and the status of their development. These and others were considered in determining the most appropriate NSTL/MSAAP wood biomass-to-energy technology. Summary details are presented here in order to provide a feeling for the state-of-the-art and of the range of combustion unit designs available for consideration. In implementing the study, TRW evaluated the systems and units listed (and others) in terms of both the specific needs of the NSTL/MSAAP plant and the characteristics of the wood biomass typically generated in southwestern Mississippi.

The second method for converting wood to energy is pyrolysis. When wood is heated in closed retorts in the absence of air, the process of decomposition is known as destructive distillation. The degree of decomposition and the ratio of products (solid, liquid, gas) depend primarily on heating temperature, moisture content, and wood species. This method of thermochemical processing can be accomplished in either of two modes, pyrolysis or gasification. In pyrolysis, the woody biomass is heated in the absence of air to temperatures where the wood substance decomposes producing combustible solids, liquids, and gases. In actual practice, a limited amount of air may be used to provide the required heat for decomposition. In gasification, the wood biomass is heated usually with limited

quantities of oxygen, although air could be used. The amount of oxygen is limited in order to produce maximum quantities of carbon monoxide and hydrogen and therefore obtain chemical energy in a conventient form. In contrast, in the combustion process the oxygen (in air) is used to the extent that the carbon is converted entirely to carbon dioxide and the hydrogen to water.

In the past pyrolysis has been used to recover products such as charcoal and methanol. The problem with recovering methanol is that this product has to compete economically with low cost conversion of petroleum. At present, the major commercial product of wood pyrolysis is charcoal for forming into briquets as fuel for backyard barbeques. Other pyrolysis processes which are designed to produce primarily oil and gas have the major weakness of not having accumulated much operating experience. It can be said that these types of pyrolysis processes have only been demonstrated on a pilot scale. The only truely commercial process and those in the most advanced stages of development are discussed in the second portion of Appendix D. All these pyrolysis systems use vertical shaft reactors with combustion of the waste near the bottom of the reactor to provide the heat for pyrolysis. The syngas produced, which has a heat content of 95-350 Btu/scf (3-14 MJ/m^3) is either used on site to generate steam or electricity, or it is quenched to form a liquid fuel.

Frequently the solids must be reduced in size and dried for efficient pyrolysis. Each pyrolysis system has a unique feed pretreatment system. Usually the feed pretreatment units are developed for the pyrolysis of Municipal Solid Waste (MSW), and modifications would be required for adapting to wood wastes. Gas cleanup systems to remove particulates from product gases are usually required. If an oil is produced, the quench water must also be treated to remove organic contaminants.

A list of essential process criterion were developed to compare biomass-to-energy conversion technologies for meeting the requirements of NSTL/MSAAP. The parameters considered essential to the process are as follows:

1) Commercial Availability. The conversion unit must be presently available for evaluation during the study period. The supplier or contractor for the unit must be experienced in processing wood as a fuel and show an understanding of the problems involved with utilizing wood and with adhering to current and projected emission standards.

   An operating unit should exist from which operating information, maintenance histories and reliability data have been obtained. This data must be available to this program.

2) Reliability. The unit(s) must be judged dependable to the extent that it can be operated to supply energy demands with only the existing heating plants (energy plants) as backup facilities.

3) Size. The energy wood unit should be sized to replace the various combinations of energy products.

4) Feed. The fuel is green wood waste from fee and buffer area harvest operations and includes harvest residues from logging operations on privately owned land. The moisture content will average 90% (dry basis)*, the heating value of dry wood will range from 8500 to 9600 Btu/lb (19.8 to 22.3 MJ/kg). An average value based on 8600 (20 MJ/kg) for pine and 7820 (18.2 MJ/kg) for hardwoods was calculated at 8520 Btu/lb (19.2 MJ/kg), dry.

5) Equipment. Systems which can make practical use of existing equipment will be given highest considerations.

6) Form of Energy Produced:

Hot water 400°F (204°C)	359,320 lb/h (0.45 kg/sec)
Heat	28.3 x 10^6 Btu/h (8.3 MW)
Steam 125 psig, (0.96 MPa), sat'd	140,000 lb/h (0.18 kg/sec)
Electric Power (peak)	10.6 MW

7) Environmental Impact
Mississippi Air and Water Pollution Control Standards
for wood fired boilers 0.3 gr/dry SCF
40% opacity
NO_x (see federal register)

8) Location. In close proximity to user.

9) Economics. A comprehensive life cycle analysis will compare the return on investment (ROI) to other alternatives (i.e., status quo).

The highest priority energy system is one which replaces the NSTL requirement for natural gas. The projected natural gas consumption for 1983 is 395 x 10^6 CF/yr (11 x 10^6 m^3/yr). The NSTL units are used to generate 340°F and 400°F (171°C and 204°C) hot water. There are two possible alternatives for utilizing wood energy to meet these requirements: Retrofit existing TAHP and CHP hot water generators to fire wood directly or fire wood pyrolysis products; or replace the existing HTHW generators with direct wood fired furnaces or wood pyrolysis systems but retain the water supply and hot water distribution systems. Either fluid-bed burners, suspension fired combustors, stoker type furnaces or a wood pyrolysis system connected to the existing HTHW generators are possibilities for the

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* $\% \text{ moisture (dry basis)} = \dfrac{\text{weight of moisture}}{\text{weight of dry wood}}$

first alternative. All three type combustors and the pyrolysis system, with furnaces designed to fire pyrolysis products, connected to the existing water supply and distribution systems, are options for the second.

The major advantage in retrofitting the existing TAHP and CHP units with wood-fired furnaces is the potential cost saving in utilizing the existing water supply system, hot water tubes and enclosures, and hot water distribution system. However, this saving is offset by the numerous disadvantages which include reluctance of stoker unit suppliers to supply a retrofit system and the required heating unit deratings if retrofitted with the other direct combustion units. The peak ratings of the existing boilers must be reduced approximately 30% to compensate for the increased ash and particulate loading on the high temperature surfaces of the furnace and on the convection tubes. With this exterior burner, there will no longer be a radiant tube section. With the increased ash loading, the velocity limit (and thus the heat transfer coefficient) must be reduced to retard erosion of the convection tube surfaces. The derated TAHP could continue to meet the output requirements operating in the current mode of operation; one TAHP on line, one in ready standby, and one off line. To meet the CHP requirements, all three derated HTHW generators would be required to operate simultaneously. In order to have a HTHW generator on ready standby, an additional wood-fired generator, or one which will fire wood pyrolysis products must be purchased.

Pyrolysis cannot be considered commercially available technology as defined by the criterion since operating histories and cost are not available. However, if a wood pyrolysis unit were installed to provide fuel for the existing HTHW generators, the generators would have to be modified to accomodate the new fuels. It has been reported that pyrolytic oil is not interchangeable with distillate or residual oils in most boiler installations without modifications to storage and pumping facilities. This is due to several properties of the pyrolytic oils: They are acidic, their properties are fairly easily changed by overheating, their properties change if the oils are allowed to evaporate at firing temperature for appreciable lengths of time; and they can form deposits on valves and heating surfaces if the system is not properly designed (Reference 15). A retrofit system to fire the pyrolysis char would be the least efficient of the alternatives. It would suffer both the efficiency loss in converting the wood to char and then the efficiency loss in firing the char, similar to the retrofit direct combustion of wood. Pyrolysis gas is low in heat content, firing at approximately 1700°F (927°C). Pyrolysis gas can be fired in existing units only with substantial furnace derating, another loss in efficient fuel utilization.

The selected energy wood system to meet the first priority energy requirements is one in which the existing HTHW generators become backups. An alternate energy system would be constructed which was designed for characteristics of wood fuel. The technology selected is direct combustion and the type unit is a stoker. The advantage the stoker furnace has over fluid-bed combustion is in the number of commercial installations and the years of operating experience. The advantage of the stoker over the suspension furnace is the lower feed preparation requirements. The major

disadvantage with a stoker furnace is that it can be purchased only as a boiler and not as a hot water generator. The characteristics for each of these furnace types are summarized in Table 15.

The second priority energy system is one which meets both the NSTL requirement for natural gas (hot water) and the MSAAP requirement for fuel oil. The system would be required to produce 359,000 pounds per hour (0.45 kg/sec) of HTHW, and 28.3 x 10^6 Btu/h (8.3 MW) of output heat at temperatures ranging from 350 to 1600°F (180 to 870°C), and 10.6 MW of electric power. The alternatives considered to utilize energy wood to meet these requirements were as follows: Install a wood-fired stoker boiler to generate steam which is utilized to produce both HTHW and electric power, and install 40 separate wood-fired furnaces for the MSAAP projectile manufacturing plant; or install a common wood pyrolysis plant and supply fuels to generate HTHW and heat in the existing and planned furnaces. Consider the electric power generated from fuel oil consumption as a part of the total electric power consumption which is the lowest priority system.

Neither of the propsed alternatives for utilizing energy wood to meet these system requirements is viable. The required HTHW output does not match the electric power output for efficient co-generation of hot water and electric power. The energy demands for 40 small furnaces would require 40 separate wood feeding systems. The cost and logistics of operating such a system are impractical. The common wood pyrolysis system would be the appropriate alternative, and should be considered for future applications.

The third priority energy system would be designed to utilize energy wood to produce 359,000 pounds per hour of HTHW (0.45 kg), 28.3 x 10^6 Btu/h (8.3 MW) of heat, 10.6 MW of electric power, and 140,000 pounds per hour (0.18 kg/sec) of 125 psig, saturated steam. Eliminating the heat and electric power requirements from this system for the reasons discussed previously, this system is essentially the one discussed under priority one plus the replacement of a coal fired boiler with a wood fired one. The incentives for replacing coal with wood fuel are possibly three: cost, unreliability of supply of coal fuel, or inability to meet EPA regulations for sulfur emissions with existing technology, (also at reasonable cost). Since these incentives may exist, the economics of this system was investigated and is described later this report. For reasons discussed previously, a stoker wood furnace was selected for this application.

The last priority system adds electric power generation to the requirements for HTHW, and steam. If a wood fired stoker boiler is utilized to generate steam to produce HTHW, an amount of electric power can be co-generated by increasing the amount of energy input into the amount of steam required to generate the HTHW. Such a system was evaluated and is discussed later in this report.

Essentially two energy wood conversion technologies were considered as applicable alternatives to replacing the NSTL/MSAAP fossil fuel plants; direct combustion and pyrolysis. Since the major criterion for the energy

Table 15. Characteristics of Conversion Technologies

CHARACTERISTICS	DIRECT COMBUSTION TECHNOLOGIES: STOKER	SUSPENSION	FLUID BED	PYROLYSIS TECHNOLOGIES: PYROLYSIS	GASIFICATION
Commercial Availability					
Contractors:	Bumstead Woolford				
Equipment Suppliers:	Detroit Stoker, Babcock & Wilcox, Zurn, Foster Wheeler, Alpha Consolidated, Agnew, Riley Stoker, Willons, Internal Boiler Works	COEN, ENERGEX	Thermal Processes, Johnson, FluiDyne, Combustion Power, Dorr-Oliver	Tech Air, Inerco, Kelly, Nichols, Purox, Enterprise, Redker-Young, BW Energy Storages, Occidental, Wallace Atkins, BSP, Torrax	Alberta Development-Thermex, Westwood Polygas, Forest Fuels
Reliability	Several hundred units in operation, over 35 years of operating experience	Several hundred in dryer and boiler applications. Units have been installed in existing boiler installations	Over 90 stream factor on operating units although currently only a small number of installations	No commercial installations in the U.S.	No commercial installations.
Available Plant Capacities	1 to 600 MM Btu/H automatic units usually larger than 3 MM Btu/H	0.5 to 60 MM Btu/H	1 to 300 MM Btu/H	Varies	Up to 35 MM Btu/H
Required Wood Fuel Properties					
Moisture, % Wet Basis (Max)	55	Supplemental fuel 1 to 5% Wood HV 10 to 15	to 65	7 to 40	15 to 25
Particle Size	Hogged wood	1/64 to 1/32-inch	Hogged wood	1" to hogged wood	Minus 1/2-inch
Particle Size Distribution	20% minus 1/4-inch	Yes	No stipulation		20% plus 3-inch
Ash,	3				
Product Properties	Sensible heat for steam generation	Sensible heat	Sensible heat	Pyrolysis oil, char and low BTU gases	Low BTU gas and charcoal. Gas flame temp. is 1700°F
Furnace Temp.	2200°F	2400°F	1600 to 1800°F	900 to 1000°F	600 to 1600°F
Efficiency					
Conversion, (Based on M.C.)	55 to 60		55 to 70	40 to 70	
Combustion,	80	100	95 to 100		
Environmental Requirements	History of particulate emission problems. Will require addition of cyclones or bag filters to meet Miss Air & Water Quality Standards	Will require additional particulate recovery equipment and ash removal equipment	Exhaust particulate loading higher than stoker requiring both cyclones and bag filters	will require particulate recovery and waste water treatment for BOD and COD.	Cyclone separators to recover char
Special Features					
Turndown Ratios	3 to 5:1 Some ash is collected on grates (and can be continuously discharged) reduces the load on the exhaust cleanup system. An auxiliary fuel is not required although it is suggested to aid operation	5 to 7:1 Pneumatic feed system required (uses 40 to 50 of combustion air) Extensive feed sizing required	3 to 3.5:1 Requires an extra blower to supply fluidizing air	3.5:1 No auxiliary fuel is required during operation Produces storable forms of fuel although oil properties change with storage conditions	No auxiliary fuel is required during operation

wood plant was that the process be available for evaluation during the report period, the selected technology was direct combustion.

To retrofit the existing NSTL hot water generators to utilize wood can only be accomplished utilizing suspension-fired or fluid-bed systems. However, wood stoker manufacturers absolutely discourage this alternative. They feel that the boiler is too integrated into the design of the furnace for such a retrofit to operate efficiently. Therefore, the economic evaluation is based on the construction of new wood-fired stoker boilers tied to the existing water supply and hot water distribution systems, with additional distribution networks where required. The existing HTHW generators will then be utilized to spare the wood-fired furnaces and therefore reduce the cost of the overall system by eliminating the need for offline furnaces.

Before the economics of the NSTL/MSAAP wood-fired energy plant are discussed, the logistics of managing a constant supply of wood to the plant will be discussed.

Logistics of Supplying Energy Wood to NSTL/MSAAP

As discussed earlier, wood is available for use in a NSTL/MSAAP energy plant from NSTL's own forest stands as residues from the primary wood industry and from harvesting operations. However, there exists much competition for the mill residues in the NSTL area. Also assembling harvesting residues, once the stands have been cut, is a labor-intensive and costly operation. It is therefore obvious that the primary source of wood fuel for NSTL/MSAAP must ultimately be the fee and buffer area forest stands.

The NSTL forest stands are stored fuel resources in the same way that coal seams, natural gas and petroleum reservoirs are stored fossil fuel resources. However, unlike the fossil fuels, the forest stands are renewable and represent a form of solar energy. In the case of NSTL, the amount of land on which the forest grows is limited. Therefore the objective of any forest management plan is to maximize the eventual energy output per unit of land utilized.

Included in Appendix E of the report is a discussion of the forest management procedures applicable to the NSTL forest stands and the future potential improvement in biomass production if these procedures are implemented. Also discussed is the volume of biomass that should be recovered from the 12,330 acres (50 km^2) of NSTL fee and buffer area forest. Since the method for harvesting is necessarily tied to the volume of material being harvested, a discussion of harvesting methods and cost of procuring forest biomass is included. Finally, the life of harvesting equipment is estimated as a basis for an economic evaluation of biomass procurement and the methods of storing the harvested biomass for an energy plant are discussed.

There has been much interest in harvesting wood as an energy source due to increasing cost of fossil fuel and increased dependence on oil imports. In the northern U.S., Rose (Reference 16) concluded that less than 60,000 acres of forest land would be required to supply a 160 megawatt

power plant continuously. The total investment would be less than $10 million, including land. Beardsley and St. George (Reference 17) found that harvesting only thinnings and logging residues was competitive with respect to cost of energy derived per ton of wood (coal at $50/ton [$55/ 10^3 kg]) and oil $.30/gal ($79/m^3).

In the southern U.S., climate, soils, native species and terrain combine to create a very favorable situation for energy from biomass. The previously mentioned comprehensive Mitre Corporation study investigated the potential of energy from biomass and selected the southern U.S. as one of the most promising regions. Specifically, short rotation energy plantations were recommended (Reference 18). The ratio of energy-out to energy-in for such plantations is some 4.0 to 1.0 even with intensive mechanization (Reference 19). This includes growing, managing and harvesting the trees and fuel preparation.

The survey of NSTL forest lands identified some 12,330 acres (50 km^2) of forest land as operable. This included 8,935 acres (36 km^2) in the fee area and 3,390 acres (14 km^2) in the buffer area. Although additional acres in the buffer area will become available as current leases expire, these lands will be returned to NSTL largely in "open" condition. Therefore the 12,330 acres (50 km^2) used in this analysis is conservative. The harvesting system must necessarily be tied to the volume of material to be removed from the site. Since the harvesting system selected was based on the conservative figure for available acreage, it may be somewhat underutilized initially but will be sufficient to handle the additional acreage at a later date.

It is suggested that a 25-year rotation be used to develop the NSTL forest into an energy plantation. With 12,330 acres (50 km^2), and a 25-year rotation, 493 acres (2 km^2) of forest land should be harvested each year. The volume harvested per acre will increase over time due to growth of the existing stands. This growth rate per acre per year is calculated to fall from a weighted average of 1.82 cords to 1.33 cords by 2003 (450 to 379 cds/km^2/yr). Harvested acres should be regenerated within the year with slash pine. The site amelioration practices outlined (Appendix E) would assure good growth of these slash pine plantations. Harvested true hardwood sites would be left to naturally regenerate. Site improvement and plantation would be established on the Sulfaquepts. If these forest management practices are followed, the sample volumes to be harvested would be as follows:

Year	Green Tons (10^3 kg) at 100% Moisture Content, dry basis	
1	22,211	(20,149)
15	84,170	(76,357)
26 on	175,877	(159,552)

These harvested volumes could only be achieved under near ideal conditions and therefore represent the upper limit of the attainable resource potential. They include volume of merchantable boles, tree tops and all understory material down to 1.0 inch (.0245 m) at diameter breast height (DBH). Year

one harvest would be 493 acres (2 km^2) at current volume levels. Year 15 harvest would be 493 acres (2 km^2) of existing stands (at current volume plus growth and 493 acres (2 km^2) of thinnings from the intensively managed plantations. Year 26 volume is the sustainable harvest level and includes thinning of 493 acres (2 km^2) of plantations plus final harvest of 493 acres (2 km^2) of plantation. The volumes would be available only using a whole-tree, in-woods chipping system for harvesting. No current long-wood systems have equipment to bring entire tops and/or understory volume out of the woods efficiently. Short-wood system would be least efficient in harvesting such volumes (Reference 20).

The energy equivalent of the annual harvest was calculated based on 8600 Btu/lb (20 MJ/kg) for oven-dried pine, 7820 Btu/lb (18.2 MJ/kg) for oven-dried hardwood, and 8520 Btu/lb (19.8 MJ/kg) for dry growth. Year one harvest is estimated to be 1.87 x 10^{11} Btu (197 x 10^{12} J); year 15 harvest is 7.15 x 10^{11} Btu (755 x 10^{12} J), and the sustained harvest from year 26 on is 15.12 x 10^{11} Btu (1595 x 10^{12} J). The yearly heating value of the harvested material at these near ideal conditions is shown in Figure 4. Also shown are the heating value equivalents of a biomass plant to replace NSTL natural gas requirements, NSTL/MSAAP natural gas plus 2 MW's, and MSAAP coal requirements.

The lower limit of the NSTL forest stand resource is estimated by considering the use of conventional long-wood harvesting systems and being much more conservative as to forest-wide potential growth. The following harvested volumes were derived:

Year	Green Tons (10^3 kg) at 100% Moisture Content	
1	6,981	(6,333)
15	36,699	(33,292)
26	105,009	(95,262)

These figures are based on a harvestable volume growth of only 1.0 cord per acre per year (227 cd/km^2/yr) for the existing stands. Further, the yield from the intensively managed plantations has been reduced by 40% from levels reported earlier. As before, 493 acres (2 km^2) of existing stands would be cut initially followed by 493 acres (2 km^2) of existing stands plus 493 acres (2 km^2) of thinnings at age 15; and the age 26 yield is the maximum attainable harvest with these reduced growth and harvesting machinery assumptions.

Translation of the reduced volumes harvested into energy equivalents is shown in Figure 5. Obviously, energy yields are greatly reduced over those presented in Figure 4. First year yield is 0.61 x 10^{11} Btu (64 x 10^{12} J), year 15 yield is 3.28 x 10^{11} Btu (346 x 10^{12} J), and the maximum level is 9.10 x 10^{11} Btu (961 x 10^{12} J). Btu harvest does not exceed 4.0 x 10^{11} Btu (421 x 10^{12} J) in this scheme until year 25. The existing types of harvesting operations in the vicinity of the NASA site could harvest this level of material since a lower utilization level is implied.

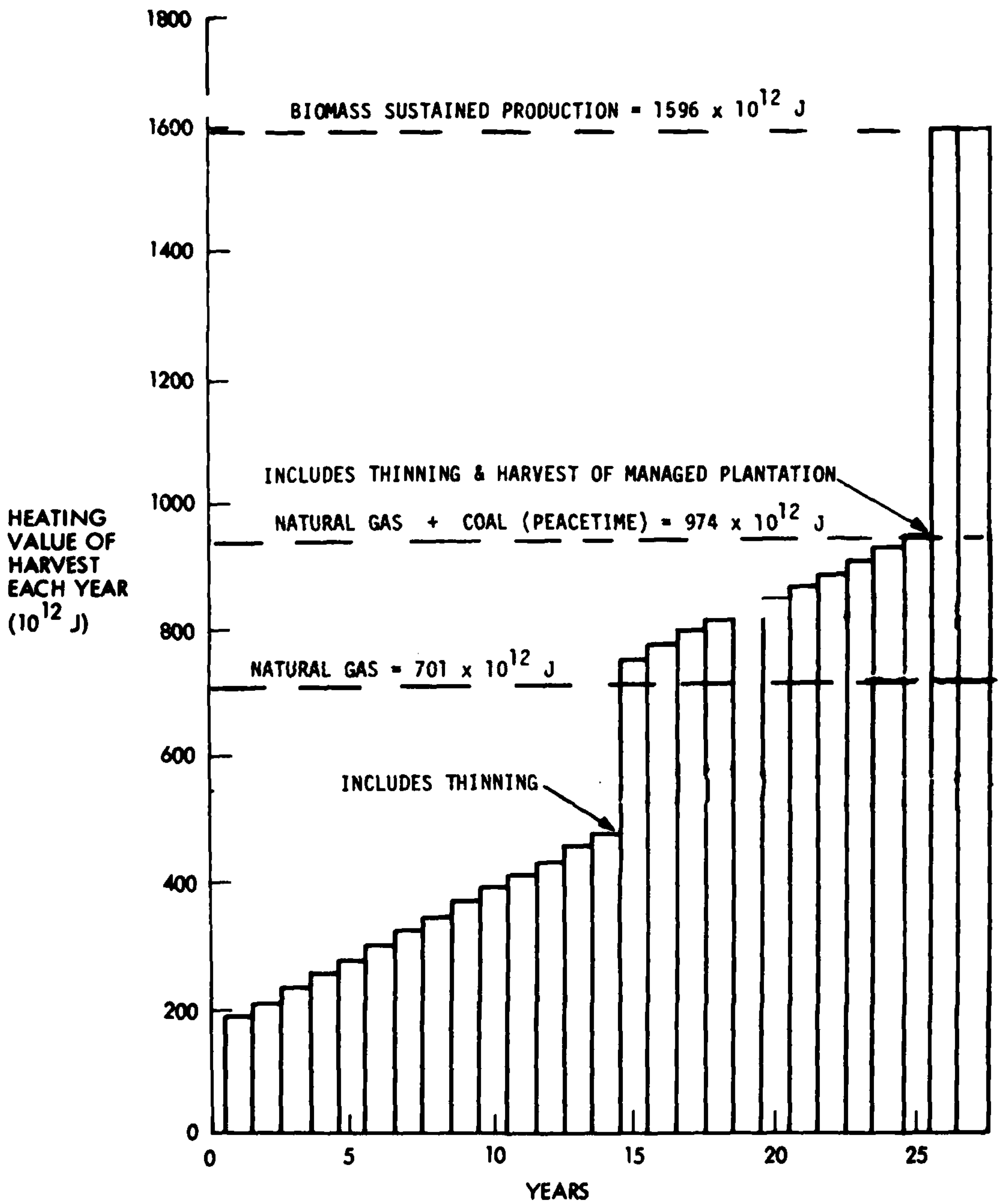

Figure 4. Energy Available From Wood Harvested from NASA Lands - Merchantable Bole and Top Volume Only and Reduced Growth - By Year

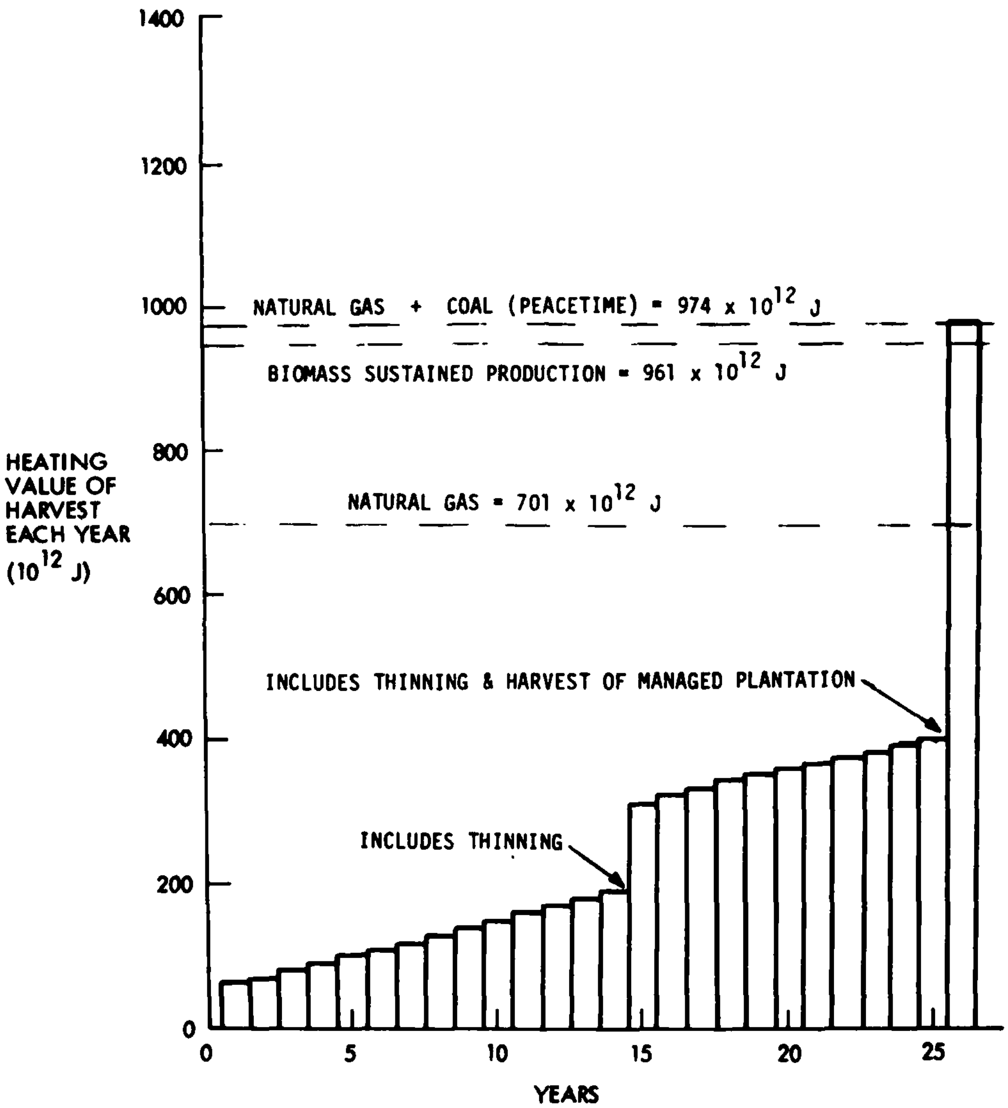

Figure 5. Btu's Available From Wood Harvested from NASA Lands-Merchantable Bole, Top Volume and Understory Volume-By Year

Actual volume of wood yielded from the NSTL forest, utilizing a whole-tree, in-woods chip harvesting system would be somewhere between the yields presented in Figures 4 and 5. However, it is reasonable to expect that actual yield would be closer to those presented in Figure 4, perhaps within 80% of the values presented. Even then, energy yield at age 15 would be sufficient to meet the energy requirements now being met by the consumption of natural gas.

The best management technique for NSTL operable forest land is one which is based on a 25 year rotation cycle. Harvesting a constant acreage over this 25 year cycle will result in an insurable volume of biomass supply. The sustaining of a constant and reliable source of biomass must be the ultimate aim of any plan designed to supply a biomass-to-energy conversion plant. The amount of biomass that would become available from NSTL lands after 11 to 14 years of scheduled harvesting and site amelioration (Appendix E), will result in annual volumes of wood sufficient to meet the consumptive requirements of a wood stoker plant generating either HTHW equivalent to the NSTL 1983 natural gas requirements or steam equivalent to the MSAAP 1983 coal consumptive level. Prior to this point in the harvesting cycle, the need to procure the additional energy wood required is highest in the early years during which the fee and buffer area forest are being converted to energy plantations.

One way to alleviate this short-fall situation, is to do a large share of the initial harvesting in stands with the highest sawlog and pole volumes. This high value material can be traded to a wood-using firm in return for residue chip volume. Trade arrangements and even purchase of mill residues in the early portion of the conversion program may fit the availability of these materials. As the value of wood as fuel becomes greater in future years, less mill residues will be available and there will be upward pressure on their value. Consequently, the future trade ratio will probably not be as high as the initially contracted one.

TRW contacted the wood procurement managers of the three largest paper companies in the NSTL/MSAAP area to ascertain if they felt that a trade agreement could be reached such that NSTL/MSAAP could recover the value of their sawtimber by trading for increased volumes of energy wood. The procurement managers were J. R. Ward of International Paper Company, Billy W. Weaver of Crown Zellerbach, and Robert Holland of St. Regis Paper Company. All three indicated that such an agreement was feasible and that trade ratios might range from 3 to 4:1 energy wood to merchantible bole.

A joint Army/NASA team visited the three paper companies to discuss the topic of furnishing wood waste to the proposed NSTL/MSAAP wood burning plant and to tour the wood burning furnace boiler facilities. The managers of all three companies indicated that they would not only be willing to work out a trade agreement with NSTL/MSAAP but that they could also provide the management of the government forest. This would eliminate the need for purchasing and operating wood harvesting equipment as a portion of the biomass-to-energy conversion plant.

Questionnaires were mailed to the three managers which included the specifics of the NSTL/MSAAP energy wood requirements and requested cost information and potential trade ratios. The completed forms are included in Appendix F.

Although the harvesting of the NSTL forest will probably be contracted to the paper companies as a part of the management program agreement, the method of harvesting and the equipment required is included in Appendix G. The annual tonnages to be harvested will approach 20,000 tons (18 x 10^6 kg) initially and increase to 168,000 tons (152 x 10^6 kg) in 26 years. Considering both the volume of material and the range of sizes of material to be harvested, an in-woods, whole-tree chipping (WTC) system is recommended (Reference 17). The following initial equipment would be required:

1	22-inch field chipper
1	Skidder with accumulating shear
2	Grapple skidders
2	Chainsaws
1	Tractor-truck
3	Chip vans (initially)
1	Pickup (3/4 ton)
1	Front-end loader (for handling at chip pile)

This equipment combination assumes all material 1-inch (.0275 m) plus in DBH will be harvested by the system.

The 1979 cost of each piece of equipment and its estimated useful life in this system is presented in Table 16. These are estimated costs and the supplier is given only to provide the source of the price quote estimation. The useful lives given are not those provided by the manufacturers, but rather are estimated useful lives based on the experience of other operations. The total cost of all equipment is \$539,000. Since some used equipment may be available and all options to improve the durability of the machinery and dependability of the system have been included, this total cost could be somewhat of an overestimate.

Since the energy wood for NSTL/MSAAP will be received at the biomass-to-energy plant in the form of wood chips, either from an in-wood harvesting operation or mill residue of sizes ranging from 1 x 1 x 3 feet (0.3 x 0.3 x 0.9 m) to sawdust, the methods for handling and storing this material were investigated. Storage and handling of wood are facilitated by having the wood in chip form. There are also economic advantages of handling wood in chip form (Reference 21). Chips should be hauled from the harvesting sites in chip vans, preferably with live-beds to aid in unloading. At the processing site the chips would be stored in large piles. A Front-end loader would be used to transport chips from the large piles to an augar system for movement to the direct-fired energy system.

Few studies have been done with reference to the impact of storage on the use of wood chips for fuel. However, conclusions regarding the

Table 16. Cost and Useful Lives of the Recommended Harvesting and Assemble Equipment

Item	Cost (each)	Useful life (yrs)	Manufacturer
22-inch Field Chipper	$141,790*	5	Morbark Inc. Winn., MI
Skidder w/accumulating Shear	68,529	4	Caterpillar, Inc. Stribling-Clements Greenwood, MS Shear - Rome Inc. Cedartown, GA
Grapple skidder	67,145	4	Caterpillar, Inc Stribling-Clements Greenwood, MS
Chainsaw	375	1	Stihl Company
Tractor-truck	45,000	4	International Trucks Jackson, MS
Chip Vans	17,000	6	Estimated from cost in other operations
Pickup	7,200	3	Ford Motor Company Garner Ford Starkville, MS
Front-end loader	81,960	6	Caterpillar, Inc. Stribling-Clements Greenwood, MS

* Heavy duty loader. Price FOB Jackson, MS.

specific gravity of wood and moisture content changes would seem to have direct relation to the use of wood chips for fuel. Reports are somewhat conflicting. Overall it appears that loss of wood substance in chip piles is restricted largely to the outer shell and that total loss would not be over 1 to 1.5% per month of storage (Reference 22).

The microbiological deterioration experienced in stored wood is of two kinds, discoloration and decay. From a fuel standpoint, it is the decay fungi that is important since it is the cause of loss in wood substance. Decay was not noticed until pine chips had been stored for 18 months in a South Carolina study (Reference 23). The role of insects in deterioration of the chip piles stored outside is discounted.

The moisture content of the chip pile is related to internal temperatures. Temperatures increase rapidly during the first 2-3 weeks of storage, reaching some 140°F (60°C) for southern pine chips and then falls to 100°F (38°C) in 3-4 months. Moisture is driven out of the high-temperature zone in the center of the chip pile in the first few weeks and appears to condense in the cooler outer zones. Thus, the fuel value of wood chips may actually be improved by a few weeks of storage.

Since so few studies have been done concerning use of wood chip piles for fuel and none for mixed species, recommendations must be given with caution. The following methods to reduce deterioration and handling problems are offered:

1) Compaction. Compaction of chips seems to decrease wood deterioration and would also mean that more wood could be stored in a given area. Blow-packing reportedly gives superior compaction and hence is recommended here. As a corollary, the chip piles should be as high as practically possible to further improve compaction. The usual wood-rotting fungi can not grow at the elevated temperatures experienced in parts of compacted chip piles.

2) Watering. Storage with water sprinkling has been a successful method of preventing fungal deterioration of roundwood until utilization. Water spraying chips during long-term storage offers no advantage over dry chip storage although there was slightly less loss of wood density (Reference 24). Water sprinkling of the chip pile is therefore not recommended, especially since it might reduce fuel value by increasing moisture content. Since there is uncertainty surrounding chip pile storage of whole-tree chips it is recommended that internal temperatures be monitored closely and a water sprinkling system be used to both marginally reduce deterioration and hold down internal pile temperatures if needed.

One incident of spontaneous combustion has been reported in a whole-tree chip pile (Reference 25). The pile was entirely hardwood species. The fire occurred in a chip pile containing 50,000 tons ($45,360 \times 10^3$ kg) of stored chips; many times the size of chip pile recommended here. Larger chip piles build up higher internal temperatures.

3) Winter Storage. Because of reduced fungal activity, a larger pile of chips can be stored during the winter with correspondingly less wood substance loss. If freezing temperatures prevail, only the outer crust of chips freezes and handling difficulties are minimal. Given the rainfall pattern in the NSTL region, a higher volume of chip storage is desirable in the winter when logging conditions are unfavorable, so this recommendation is a good match.

4) Foundation. Considerable amounts of dirt and rot are sometimes introduced when unsurfaced bases are used for chip piles. The use of surfaced areas can effectively decrease deterioration of chips at the bottom of chip piles and is recommended here.

5) Storage Time. Chips have been stored in piles for years, but most southern pulp and paper mills try to use their chips within six to nine months. Hardwood chips can not be stored as long as softwood chips because of greater deterioration and so a storage time of no more than three to six months is recommended

6) Fungicides. Use of fungicides is an effective chemical means of controlling wood substance deterioration in chip piles. However, given the very low anticipated loss without treatment and the high cost of fungicide application, it is not recommended for use.

The whole-tree, in-woods chipping system recommended for the energy from wood program at NSTL can generate a large volume of wood chips very quickly. However, inclement weather can prevent harvesting or at least increase the risk of damage to the site from compaction, etc. to the extent that harvesting operations must be halted. Consequently, an inventory of whole-tree chips must be maintained.

This inventory should be kept close to the processing plant. In-woods storage is not needed. As a minimum, a two-month chip supply from the harvesting operation should be maintained at all times. This will prevent temporary harvesting conditions from slowing plant operation. An inventory equivalent to the volume that could be harvested by the whole-tree system in 44 days (working days) should be maintained at all times. A single chip pile contains sufficient wood chips to provide a two-month supply from the whole-tree harvesting system without "trade" arrangements.

If additional inventory is necessary during the winter months more wood chip piles should be started rather than making the single pile larger. This will facilitate rotation of the chips and reduce internal heat buildup within the chip pile. Chip use on a first-in, first-out basis should not be of great concern for an individual pile. The first-in, first-out inventory management system offers little advantage over the length of storage period proposed here and is more costly (Reference 26).

Little data are available regarding storage and handling whole-tree chips for fuel. Personnel from an on-going operation make the following suggestions:

1) Stack the chip pile as high as possible.

2) There should be no problem in mixing pine and hardwood chips if chips are for fuel.

3) The heat buildup through the first 20 days causes the wood sugar in whole-tree chip piles to begin breaking down. Storage of whole-tree chips for fuel for much over 40-60 days brings a corresponding increase in handling problems. The chips tend to stick together.

4) It was noted that handling problems caused by chips sticking together can take place inside the chip vans if the whole-tree chips are left inside these confined vans for more than four to five days.

NSTL Biomass to Energy Conversion Plant

The feasibility of utilizing wood to supply energy depends on the economics of procuring the wood fuel; delivering, storing, sizing and feeding the fuel to a conversion system; and then transforming the fuel to a form of energy usable to NSTL. In order to determine this cost of energy, it is necessary to design a conversion process at the conceptual level so that the cost of the major equipment items can be estimated. Then it is necessary to determine the cost of installing and operating such a plant. From these two cost estimates, the cost of energy from biomass at NSTL can be obtained.

In this and the next two sections the process description, process cost, operating cost, and biomass energy cost of three NSTL/MSAAP units are discussed. The first one was designed to meet the NSTL requirements for HTHW. The second was designed to produce HTHW for NSTL plus co-generated electric power for the NSTL/MSAAP power grid. The final system was designed to utilize energy wood to generate saturated steam for MSAAP.

The wood fired system presented in Figure 6 was designed to supply the NSTL 1983 HTHW requirement by firing 74,000 TPY (67×10^6 kg) of energy wood. At daytime operations, the NSTL demand is 359,300 lb/hr (162,984 kg/hr) of 340 to 400°F (171 to 204°C), 260 to 425 psig (1.8 to 2.9 MPa) hot water. The turndown rate is 167,000 lb/hr (75,749 kg/hr) of hot water. The design fuel is energy wood, mostly southern pine, with

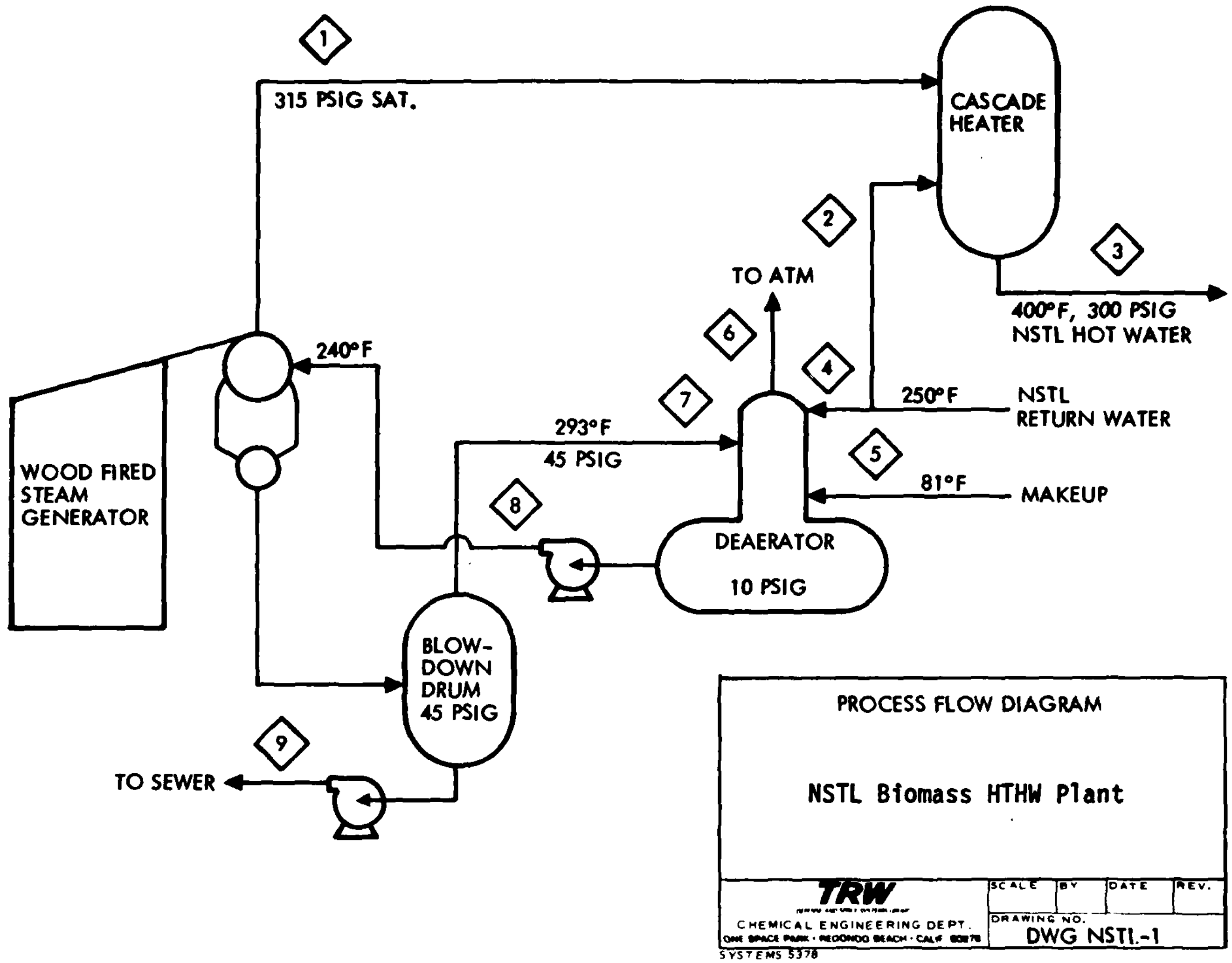

Figure 6. Process Flow Diagram

90% moisture content and an average heating value of 4,484 Btu/lb (10.42 x 10^6 J/kg) on a wet basis. The estimated average ultimate analysis of energy wood is shown in Table 17.

Table 17. Average Ultimate Analysis of Energy Wood, dry basis

	Weight %
Carbon	52
Hydrogen	6
Sulfur	.02
Nitrogen	.1
Oxygen	41
Ash	1
HHV, Btu/lb dry	8520

As-received energy wood contains fines (sawdust) in addition to oversized material. Oversized material should not exceed 50% and fines should not exceed 20%. Fines are all sizes under 1/4 inches (.64 cm) and oversized materials are all sizes from 3 inches (7.6 cm) up to one foot (0.3 m) by three feet (.91 m) length. Energy wood fired at the boiler is specified at 3 inches by 3 inches by 3 inches (7.6 cm) nominal size with fines not to exceed 20%.

The new system will be design to meet the NSTL HTHW demand and operate in two modes:

Daytime

Hot water generated:

Rate, lb/hr (kg/hr)	359,300	(162,984)
Temperature, °F (°C)	400	(205)
Pressure, psig (MPa)	300	(2.17)

Operating schedule:

11 hours per day
5 days per week
250 days per year
2750 hours per year

Turndown:

Hot water generated:

Rate, lb/hr (kg/hr)	167,000	(75,749)
Temperature, °F (°C)	400	(205)
Pressure, psig (MPa)	300	(2.17)

Operating schedule:

13 hours per day, 5 days per week
24 hours per day, 2 days per week
115 days per year
6010 hours per year

A simplified flow diagram of the system designed to convert heat from the combustion of energy wood to HTHW is shown in Figure 6. The water and steam rates for the numbered streams are shown in Table 18.

The boiler is fired with energy wood at a rate of 14 TPH (12,700 kg/hr) during daytime operations, generating 82,000 lb/hr (37,240 kg/hr) of 426°F (219°C), 315 psig (2.27 MPa) steam (stream 1). The output duty of the wood-fired boiler is 82 x 10^6 Btu/hr (23.95 MW). The steam flows to the hot water generator where it combines with 367,000 lb/hr (166,467 kg/hr) of 250°F (121°C) boiler feedwater (stream 2) in a direct contact hot water generator. The rate of hot water generated (stream 3) is 449,100 lb/hr (203,730 kg/hr). The duty of the hot water generator is 67 x 10^6 Btu/hr (19.56 MW). Boiler feedwater at 240°F (116°C) is fed at a rate of 84,600 lb/hr (38,373 kg/hr) to the boiler steam drum (stream 8) The NSTL return water at 250°F (121°C) is divided into two streams. Approximately 367,000 lb/hr (166,467 kg/hr) is pumped to the hot water generator (stream 2) while the remaining 20% is pumped to the deaerator (stream 4). Makeup water (stream 5) replenishes losses from blowdown (stream 9) and water vapor entrained during deaeration (stream 6).

For the purpose of discussion, the NSTL Wood fired HTHW plant has been divided into seven functional systems: Front end wood handling, steam generation, ash removal, boiler feedwater, hot water generation, water treating and condensate storage and hot water transmission. Each system is depicted in the following process flow diagrams, Figures 7 through 11. The detailed system descriptions are in Appendix H.

The front end wood handling system contains the equipment necessary to receive, transport, size, store, reclaim and feed wood chips and fines (sawdust) to a large wood fired boiler plant. Energy wood is unloaded from trailers containing about 25 tons (22.7 x 10^3 kg) per load at the trailer dumper (A-1). The dumper unloads five to six trailers per hour (125 TPH [113.4 x 10^3 kg/hr]) into a 30 ton (27.2 x 10^3 kg) hopper. The wood chips and fines are unloaded from the hopper via a live bottom feeder and conveyed to the wood receiving conveyor (L-1). This conveyor feeds an electromagnetic separator (S-1) where metal objects are removed from the wood chips. The wood is then fed to the overs disc screen (S-2) where the oversize material is separated. This screen passes three inches (7.6 cm) or less to the hogged wood discharge belt conveyor (L-2) for delivery to the wood pile. The oversized material is fed from S-2 to the wood hogger (A-2) to be reduced to nominal three inches (7.6 cm) size.

The sized energy wood is piled by the stacking conveyor part of the wood pile stacker/reclaimer assembly (L-3). The wood pile, 300 x 300 feet (91.4 x 91.4 m) will hold 14,800 tons (13,426 x 10^3 kg) or about 2-1/2 months of fuel supply at an average boiler feed rate of 8.4 TPH (7.62 x 10^3 kg/h). Reclaimed energy wood is separated into chips and fines by a disc screen (S-3) and stored separately in live bottom bins B-2 and B-1 in order that the amount of fines in the boiler feed can be controlled.

Table 18. NSTL Hot Water Generator Water and Steam Rates

Stream No.	1	2	3	4	5
Pressure, psia	330	25	315	25	14.7
(MPa)	(2.27)	(.17)	(2.17)	(.17)	(.10)
Temperature, °F	426	240	400	240	81
°C	(219)	(116)	(205)	(116)	(27)
lb/hr (kg/hr)					
Water, lb/hr		367,000	449,100	82,100	12,900
(kg/hr)		(166,467)	(203,707)	(37,240)	(1,315)
Steam, lb/hr	82,100				
(kg/hr)	(37,340)				
Total, lb/hr	82,100	367,000	449,100	82,100	12,900
(kg/hr)	(37,340)	(166,467)	(203,707)	(37,240)	(1,315)

Stream No.	6	7	8	9
Pressure, psia	25	60	25	60
(MPa)	(.17)	(.41)	(.17)	(.41)
Temperature, °F	240	293	240	293
°C	(116)	(145)	(116)	(145)
lb/hr (kg/hr)				
Water, lb/hr			84,600	2,100
(kg/hr)			(38,374)	(952)
Steam, lb/hr	800	400		
(kg/hr)	(363)	(181)		
Total, lb/hr	800	400	84,600	2,100
(kg/hr)	(363)	(181)	(38,374)	(952)

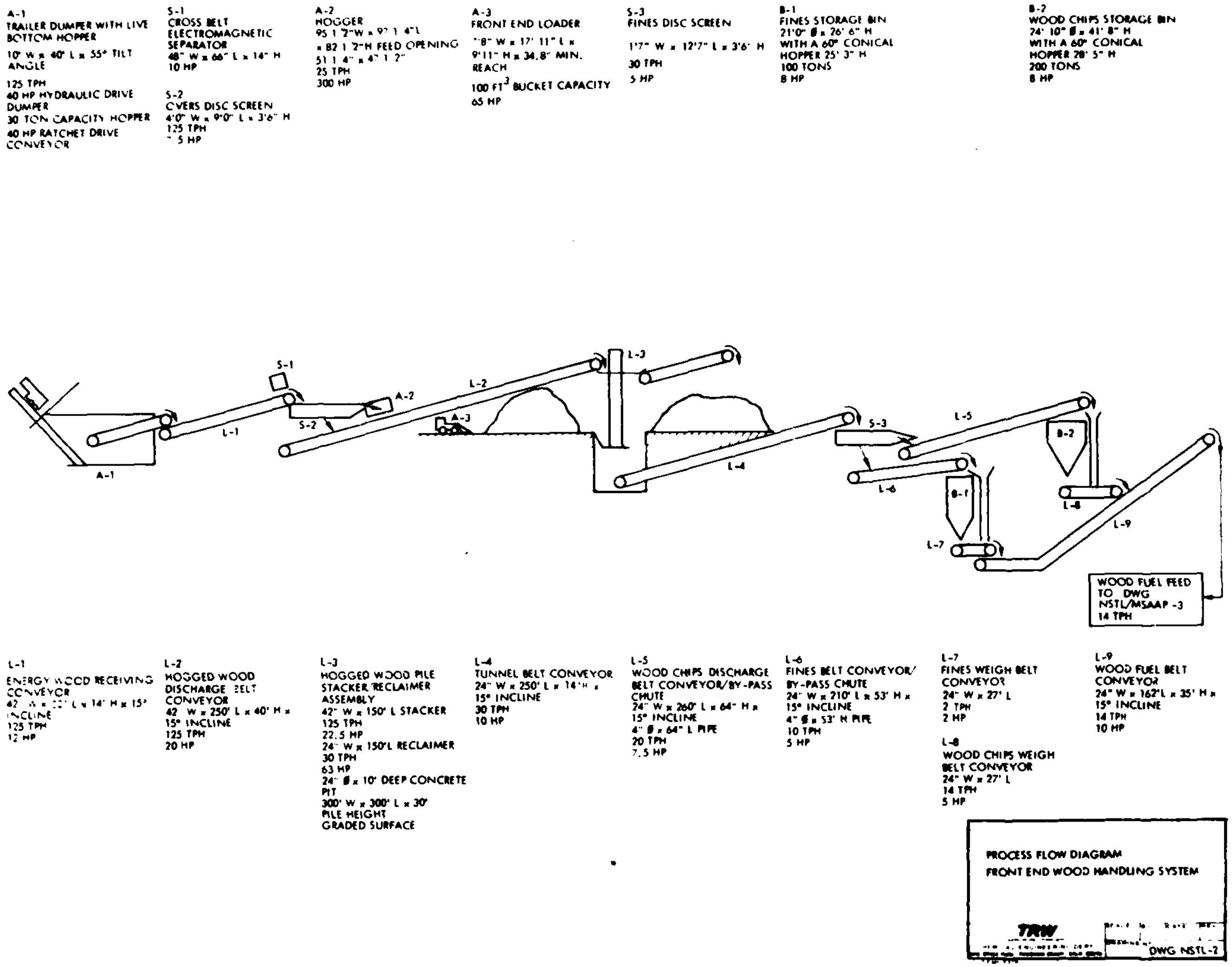

Figure 7. Process Flow Diagram - Front End Wood Handling System

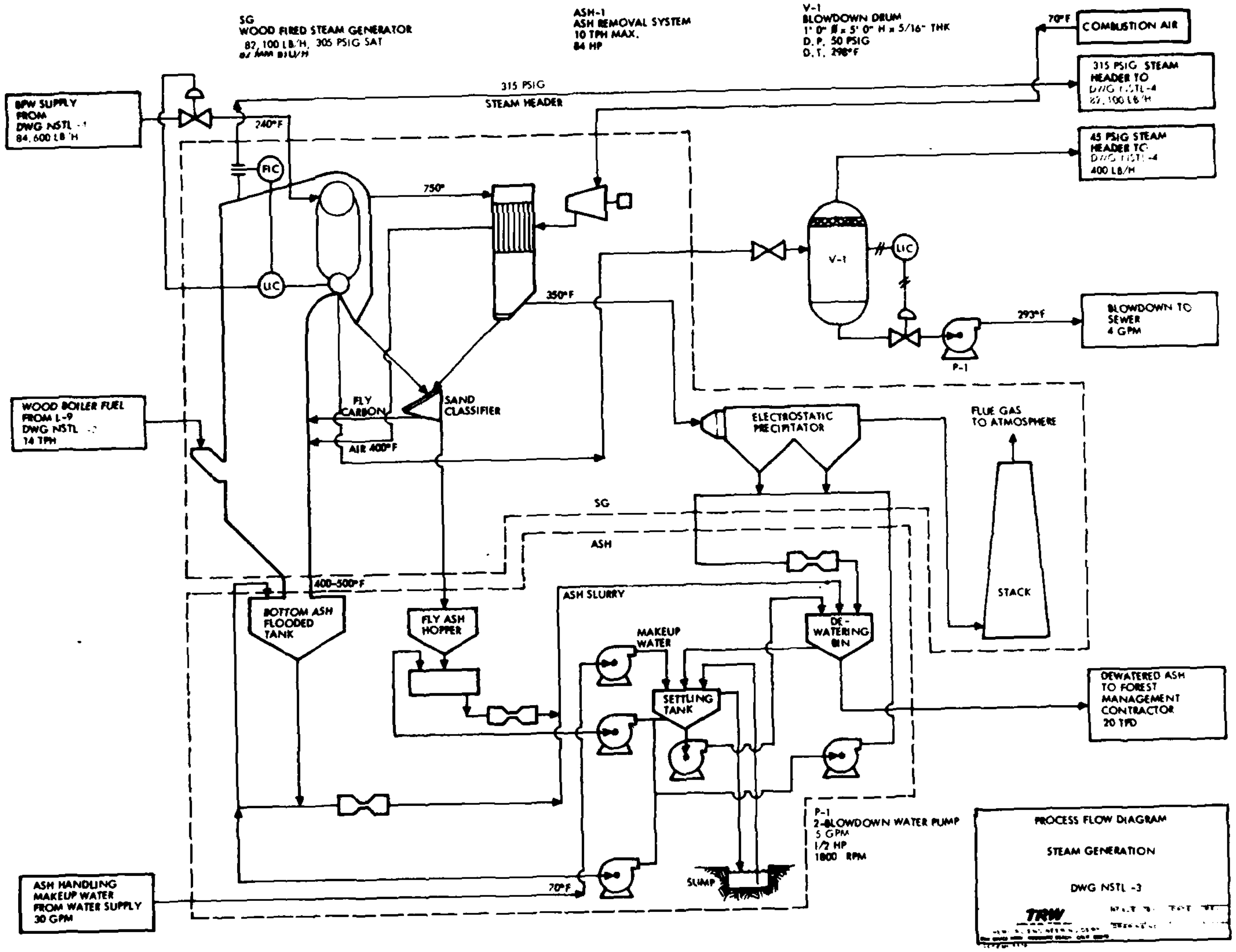

Figure 8. Process Flow Diagram - Steam Generation and Ash Removal.

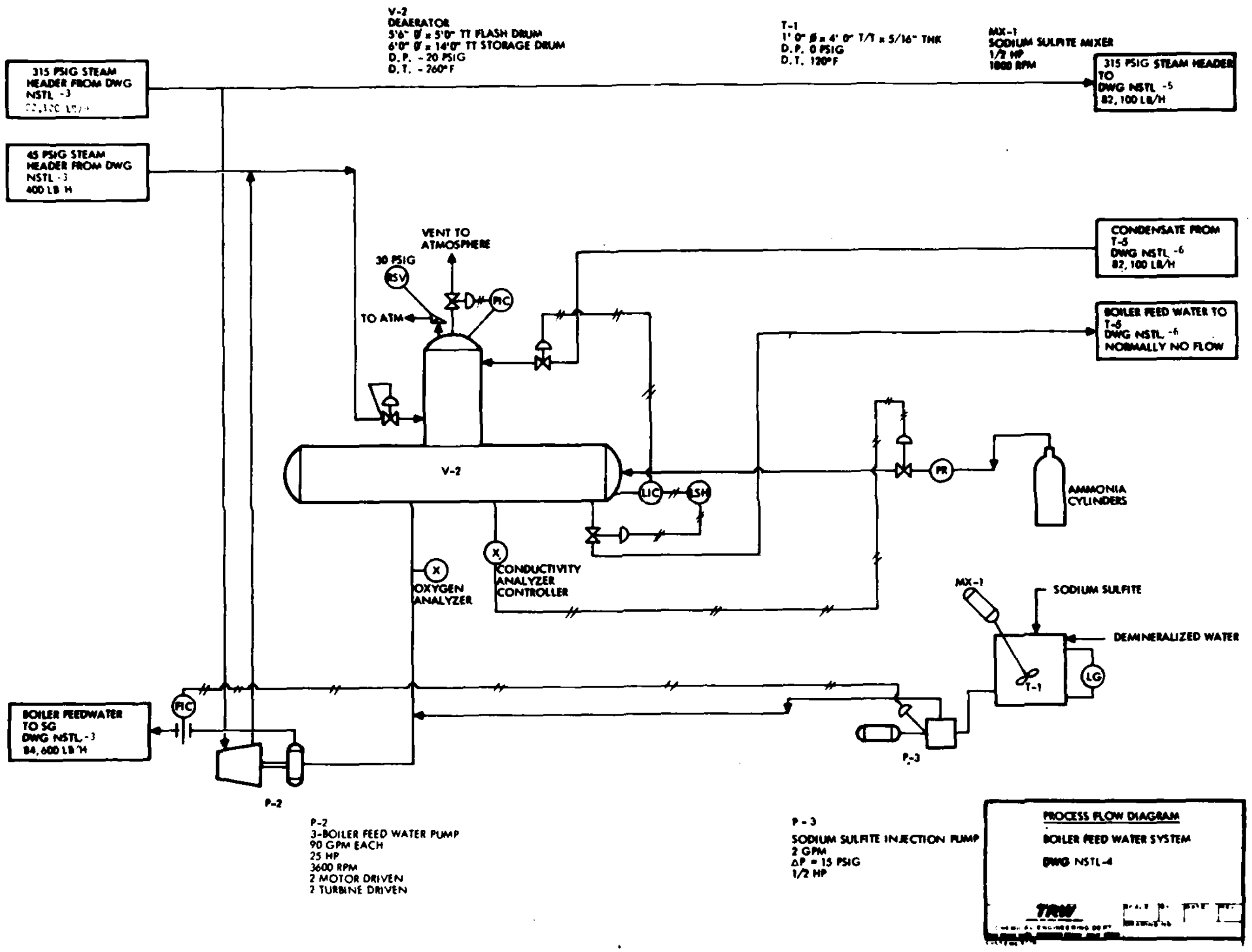

Figure 9. Process Flow Diagram - Boiler Feed Water System

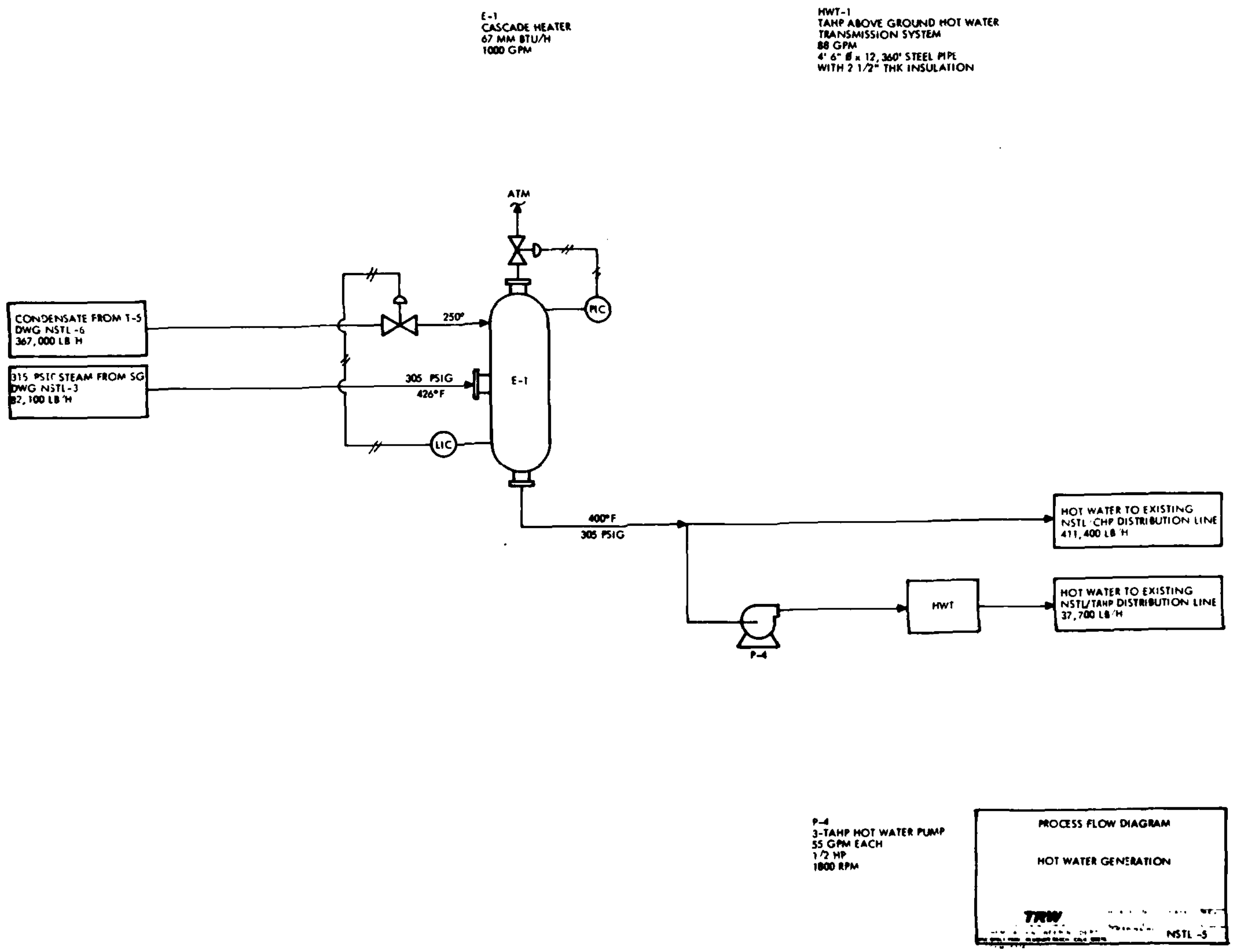

Figure 10. Process Flow Diagram - Hot Water Generation

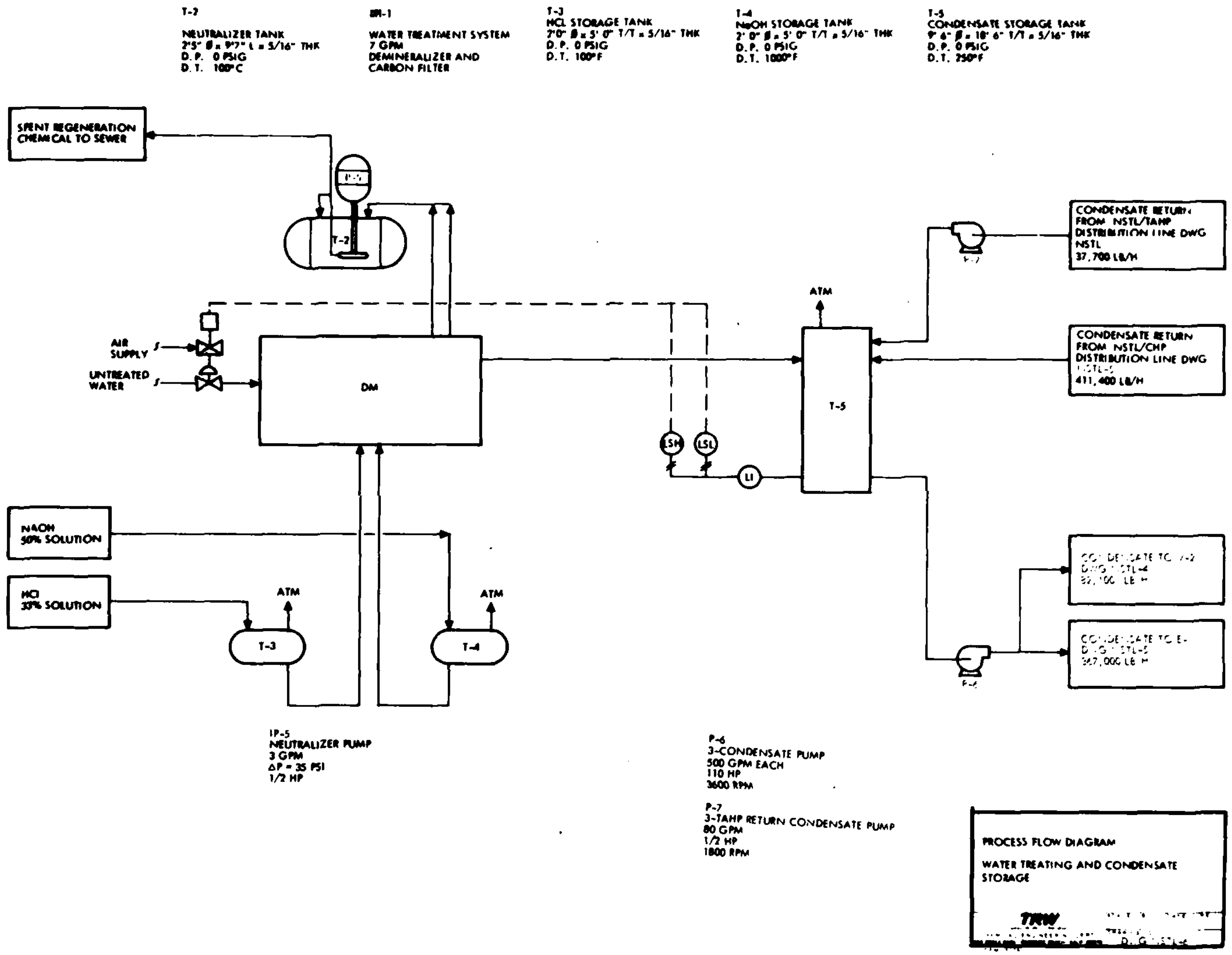

Figure 11. Process Flow Diagram - Water Treating and Condensate Storage

A wood fired steam generator (SG) with a daytime fuel feed rate of 14 TPH (12.70 x 10^3 kg/hr) supplies the process steam demand of 82,000 lb/hr (37,240 kg/hr) steam at 315 psig (2.27 MPa) saturated. The steam generator has an output duty of 82 x 10^6 Btu/hr (23.95 MW) operating at an overall efficiency of 68%. The wood fuel is 90% moisture content with a heating value of 4,484 Btu/lb (10.42 x 10^6 J/kg) on a wet basis.

Boiler feedwater pumps (P-2A-c) feed 240°F (115°C) water from the deaerator (V-2) to the steam drums of the steam generator at 330 psig (2.27 MPa). Due to the high quality of the boiler feedwater, blowdown is assumed to be only 3% of steam generated. The continuous blowdown from the steam drum is flashed to 45 psig (.41 MPa) in the blowdown drum (V-1) where the flashed steam is sent to the steam system and the condensate is purged from the system. The blowdown water is assumed to be sewered.

The steam generator is provided with a force draft fan to supply combustion air, which is preheated in the air preheaters by exchange with the hot flue gases. The flue gases are withdrawn from the steam generator by an induced draft fan. Fly ash and fly carbon are separated from the flue gases by mechanical separators and then an electrostatic precipitator in order to meet federal and local particulate emission standards. The fly carbon is separated from the fly ash through a sand classifier. The fly carbon is reinjected into the combustion chamber while the fly ash is collected in hoppers. The boiler is provided with sootblowers, controls, traveling or inclined grate stoker, ash hopper, refractory, boiler trim and auxiliary burners and ignitors. The process flow diagram for the steam generation is shown in Figure 8 (Dwg NSTL-3).

Wood fired systems have lower combustion efficiency than furnace systems fired with either coal, fuel oil or natural gas. This results in a high content of unburned wood in the ash. With an estimated average ash content of 1% and an 80% combustion efficiency of energy wood, approximately 1.3 TPH (1.18 x 10^3 kg) of ash is generated during daytime operation. A large portion of ash collected is from the furnace grates (bottom ash). The remaining ash is from boiler hoppers, air heater hoppers and mechanical dust collector hoppers (fly ash). Bottom ash will be stored in a flooded hopper. Each eight hours the recovered fly ash will be added to the bottom ash, dewatered and discharged to dump trucks for delivery to the Forest Management Contractor for use as a soil conditioner. The ash contains potash and potassium which is beneficial to the postassium deficient soil at NSTL. The ash handling system flow diagram is shown in Figure 8 (Dwg NSTL-3).

The boiler feedwater system depicted in Figure 9 provides deaerated treated water to the boiler. Condensate at 250°F (121°C) is returned to the deaerator column (V-2) from the condensate return pump (P-5A). The deaerator operates at 15 psig (0.2 MPa) and 250°F (121°C) flashing inert

gases to the atmosphere and removing dissolved oxygen in excess of 0.005 cc/liter from the feedwater. The pH of the boiler feedwater is maintained at the 9-10 range by the automatic injection of anhydrous ammonia into the deaerator storage drum. Three two-stage, 3600 RPM boiler feedwater pumps (P-2A-C) transfer the 15 psig (0.2 MPa) and 240°F (116°C) boiler feedwater to the steam drums.

Steam generated from the boiler (SG) is delivered at the cascade heater (E-1) as proposed by the International Boiler Works with a 10 psi (69 kPa) line loss. At daytime operating loads, 82,100 lb/hr (37,240 kg/hr) of 305 psig (2.2 MPa), 426°F (219°C) steam combines with 250°F (116°C) of return water generating 449,150 lb/hr (203,730 kg/hr) of hot water at 400°F (205°C), 305 psig (2.2 MPa). At the turndown rate, 38,000 lb/hr (17,236 kg/hr) of steam is condensed with 170,000 lb/hr (77,110 kg/hr) of boiler feedwater to meet the NSTL demand. The design duty of E-1 is 66.7 x 10^6 Btu/hr (99.54 MW) with a turndown duty of 37.8 x 10^6 Btu/hr (11.08 MW). The E-1 design pressure is 350 psig (2.51 MPa). Of the 449,150 lb/hr (203,730 kg/hr) of hot water generated from E-1, 37,700 lb/hr (17,100 kg/hr) must be pumped (P-4) to the TAHP which is located two miles (3.2 km) from the proposed wood fired HTHW generating plant site, located near the CHP. It is planned to circulate the HTHW from the TAHP in the existing pipelines. The remaining 411,400 lb/hr (186,607 kg/hr) of hot water can be circulated through existing CHP pumps and pipelines. Therefore, the only new pipeline required is from the old CHP site to the TAHP site. The hot water generation flow scheme is presented in Figure 10 (Dwg NSTL -5).

A demineralizer unit (DM) consisting of carbon filters, strong acid cation exchanger, strong base anion exchanger, regeneration system and local control panel provides high quality makeup water to the condensate storage tank (T-5). The required makeup at daytime operation is 2930 lb/hr (1329 kg/hr). The demineralizer unit (DM) is designed to operate at 6 GPM (1.36 m^3/hr). The condensate storage tank (T-5) collects and holds 449,100 lb/hr (203,707 kg/hr) of returned condensate from the NSTL heating loads plus the treated makeup water from the demineralizer unit (DM). The 82,100 lb/hr (37,240 kg/hr) of condensate from T-5 is returned to the deaerator (V-2) and 367,000 lb/hr (166,467 kg/hr) to the cascade heater (E-1) by the condensate return pump (P-6A-C) using two pumps with one pump as a spare. The pumps are designed for 500 GPM (113.5 m^3/hr) each with a discharge pressure of 305 psig (2.20 MPa). The process flow diagram for the water treatment system is shown in Figure 11 (Dwg NSTL-6).

Since the single energy wood HTHW system will supply hot water to both the previous CHP and the TAHP users, a hot water transmission system will be required. From a location near the existing CHP, 37,700 lb/hr (17,100 kg/hr) of hot water for the test area is pumped (P-4A&B) over two miles (3.2 km) in an above ground insulated pipeline and returned through a separate pipeline.

Included in Appendix H is a list of the major processing equipment required for the NSTL HTHW plant, equipment descriptions, and installed cost estimates. The installed equipment cost is factored from the FOB cost and includes the following:

- FOB Equipment
- Field Materials
  - Equipment
  - Piping
  - Concrete
  - Steel
  - Instruments
  - Electrical
  - Insulation
  - Paint
- Site Preparation
- Material Erection
- Direct Field Labor
- Indirect Costs
  - Freight
  - Taxes
  - Construction Overhead
  - Fringe Benefits
  - Labor Burden
  - Field Supervision
  - Temporary Facilities
  - Construction Equipment
  - Small Tools
  - Miscellaneous Field Costs
  - Contractor Engineering

The capital equipment costs, in second quarter 1979 dollars, were obtained from various sources: Technical literature, equipment suppliers, and internal (TRW) costing data. Cost escalation from dated literature sources is based on the Marshall and Swift Cost Index.

NSTL/MSAAP Biomass to Energy Conversion Plant

The wood fired system presented in Figure 12 supplies the NSTL hot water requirement and generates power accordingly. At daytime operations, the NSTL demand is 359,300 lb/hr (162,984 kg/hr) of 400°F (205°C), 300 psig (2.17 MPa) hot water. The turndown rate is 167,000 lb/hr (75,749 kg/hr) of hot water. Electric power is co-generated in a back pressure turbine equivalent to 2.2 MW during daytime operations and 0.9 MW at turndown rates.

Fuel fired is energy wood, mostly southern pine, with 90% moisture content and an average heating value of 4,484 Btu/lb (10.42×10^6 J/kg) on a wet basis. The estimated average ultimate analysis of energy wood is shown in Table 17 (page 55).

The system is designed to meet the NSTL HTHW demand and co-generate electric power. The two design modes of operation are as follows:

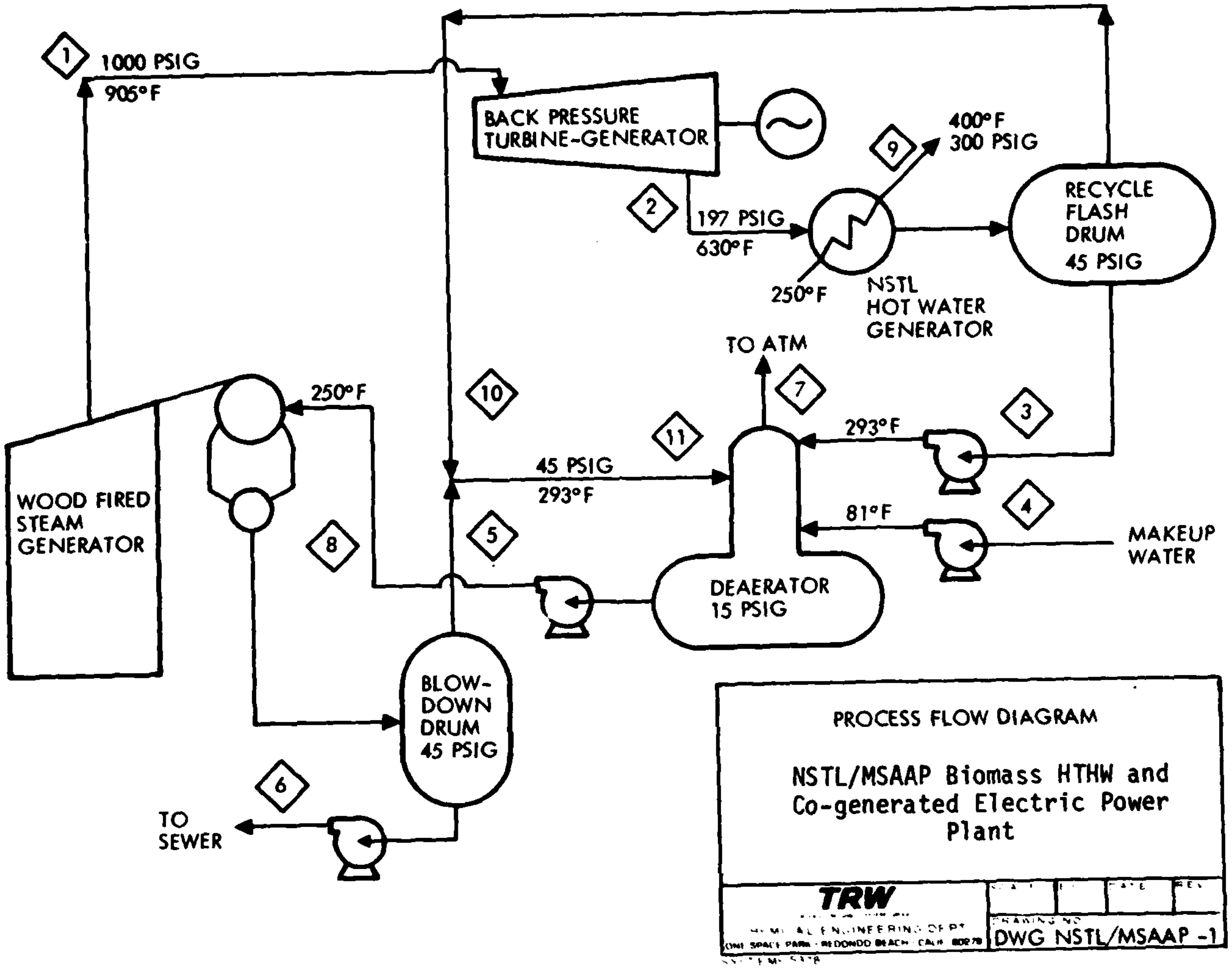

Figure 12. **Process Flow Diagram**

Daytime		
Hot water generated:		
Rate, lb/hr (kg/hr)	359,300	(162,984)
Temperature, °F (°C)	400	(205)
Pressure, psig (MPa)	300	(2.17)

Electric power generated, MW: 2.2

Operating schedule:
- 11 hours per day
- 5 days per week
- 250 days per year
- 2750 hours per year

Turndown:		
Hot water generated:		
Rate, lb/hr (kg/hr)	167,000	(75,749)
Temperature, °F (°C)	400	(205)
Pressure, psig (MPa)	300	(2.17)

Electric power generated, MW: .9

Operating schedule:
- 13 hours per day, 5 days per week
- 24 hours per day, 2 days per week
- 115 days per year
- 6010 hours per year

Figure 12 is a simplified flow diagram of the plant. The water and steam rates of the numbered streams are shown in Table 19. The hot water generated for NSTL use (stream 9) is 25% in excess of the required demand rate. At daytime operation 65,900 lb/hr (29,890 kg/hr) of 900 psig (6.31 MPa), 900°F (483°C) steam (stream 1) drives the turbine generating 2.2 MW of electric power and 0.9 MW at turndown rate requiring only 38,000 lb/hr (17,236 kg/hr) of steam. This shows the complete dependence of the amount of power generated to the hot water demand of the operation.

The boiler feedwater fed at the steam drum (stream 8) of the wood fired steam generator is at 250°F (121°C). The boiler, fired with energy wood at a rate of 14 TPH (12,700 kg/hr), generates steam at 1000 psig (7.0 MPa), superheated to 905°F (485°C) during daytime operations. The boiler output duty is 81.2 x 10^6 Btu/hr (23.80 MW).

Allowing for a 10% line loss, delivered inlet steam condition at the turbine (stream 1) is 900 psig (6.31 MPa), 900°F (483°C). At daytime operation, 2.2 MW of electric power is generated from the turbine-generator with a back pressure of 235 psig (1.72 MPa). This is assuming a turbine-generator efficiency of 72% as advised by turbine manufacturers such as the Terry Corp. and Trane. The turbine back pressure is at the inlet condition requirement of the hot water generator, 197 psig (1.46 MPa). This provides a 5°F (2.77°C) approach at the heat exchanger. The 235 psig (1.72 MPa) back pressure (stream 2) allows a 15% line loss from the turbine to the heat exchanger.

Table 19. NSTL/MSAAP Hot Water and 2.0 MW Power Plant

Stream No.	1	2	3	4	5	6
Pressure, psia	1,015	250	60	14.7	60	60
(MPa)	(7.0)	(1.32)	(.34)	(.10)	(.34)	(.34)
Temperature, °F	900	630	293	81	293	293
(°C)	(485)	(332)	(145)	(27)	(145)	(145)
lb/hr						
(kg/hr)						
Water, lb/hr			65,400	4,700		1,400
(kg/hr)			(29,665)	(2,132)		(635)
Steam, lb/hr	65,900	65,900			600	
(kg/hr)	(29,891)	(29,891)			(272)	
Total, lb/hr	65,900	65,900	65,400	4,700	600	1,400
(kg/hr)	(29,891)	(29,891)	(29,665)	(2,132)	(272)	(635)

Stream No.	7	8	9	10	11
Pressure, psia	30	30	315	60	60
(MPa)	(.20)	(.20)	(2.17)	(.34)	(.34)
Temperature, °F	250	250	400	293	293
(°C)	(121)	(121)	(205)	(145)	(145)
lb/hr					
(kg/hr)					
Water, lb/hr		67,700	449,100		
(kg/hr)		(30,799)	(203,707)		
Steam, lb/hr	3,300			500	1,100
(kg/hr)	(1,497)			(227)	(499)
Total, lb/hr	3,300	67,900	449,100	500	1,100
(kg/hr)	(1,497)	(30,799)	(203,707)	(227)	(499)

The hot water generator supplies the NSTL hot water requirement of 449,150 lb/hr (203,730 kg/hr) during daytime operations (stream 9). This is generated by heating NSTL return water with turbine spent steam (stream 2) from 250°F (121°C) to 400°F (205°C) (stream 9). The duty of the hot water generator is 70 x 10^6 Btu/hr (20.5 MW) during daytime operation.

The boiler feedwater rate (stream 8) during daytime operation is 68,000 lb/hr (30,844 kg/hr). This is based on the rate of condensate return (stream 3). Makeup water (stream 4) replenishes losses at blowdown (stream 6) and steam flashed during deaeration (stream 7).

Process Description

This NSTL/MSAAP plant has been divided into eight functional systems. Three are identical to the systems described for the NSTL plant: Front end wood handling (Figure 7), ash removal and hot water transmission systems. The steam generation system (Figure 13) is similar to the NSTL plant except that the boiler is designed to generate 1000 psig (7 MPa) steam superheated to 905°F (485°C). The boiler feedwater system is similar to the NSTL system except that the circulation rates are lower and pump power requirements are higher (Figure 14).

Steam generated from the boiler (SG) is delivered at the turbine (D-1) with a 10% line loss. At daytime operation, 65,900 lb/hr (29,891 kg/hr) of 900 psig (6.3 MPa), 900°F (482°C) steam, drives a back pressure turbine generating 2.2 MW of electric power. At turndown rate, D-1 will generate only 0.9 MW of electric power with 30,200 lb/hr (13,698 kg/hr) of steam.

Exhaust steam from the turbine at 235 psig (1.72 MPa) and 630°F (333°C) flows to the hot water generator (E-1). At daytime operation, 65,900 lb/hr (28,891 kg/hr) of 197 psig (1.46 MPa) and 630°F (333°C) turbine exhaust steam is used to heat 449,150 lb/hr (203,730 kg/hr) of NSTL return water from 250°F (121°C) to 400°F (205°C) in a counter current shell and tube heat exchanger (E-1) consisting of a desuperheater/ condenser and a subcooler. The subcooled steam at 300°F (149°C) is flashed at 45 psig (.41 MPa) to produce steam for the deaerator. E-1 is designed for 350 psig (2.51 MPa) and a peak duty of 70 MM Btu/hr (20.5 MW). The mean temperature difference at the desuperheater/condenser is 171°F (76°C) and 81°F (28°C) at the subcooler. The process flow diagram for the hot water and power operation system is Figure 15.

The water treating and condensate storage system is similar to the NSTL system except the required makeup water at daytime operation is 4705 lb/hr (2134 kg/hr). Therefore demineralizer unit (DM) is designed to operate at 10 GPM (2.27 m^3/hr). The condensate storage tank (T-5) collects and holds 449,100 lb/hr (203,707 kg/hr) of returned condensate from the NSTL heating loads plus the treated makeup water from the demineralizer unit (DM) and 65,400 lb/hr (29,665 kg/hr) of recycle condensate from V-3. The tank is vented to the atmosphere to allow for flashing steam from the returned condensate. The 449,100 lb/hr (203,707 kg/hr) of condensate from T-5 is returned to the subcooler section of the shell and tube heat exchanger and 70,105 lb/hr (31,800 kg/hr) of makeup water and recycle

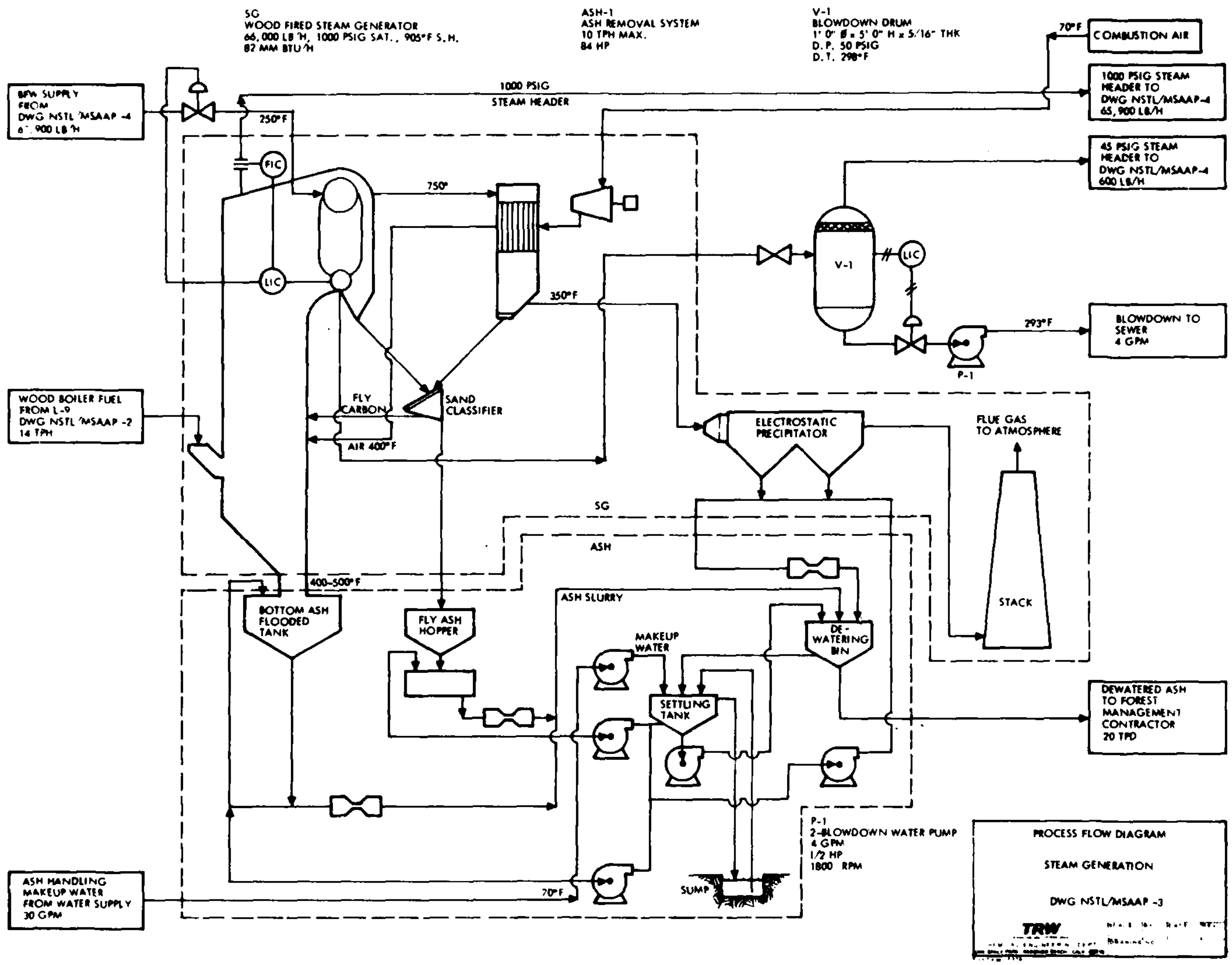

Figure 13. Process Flow Diagram - Steam Generation

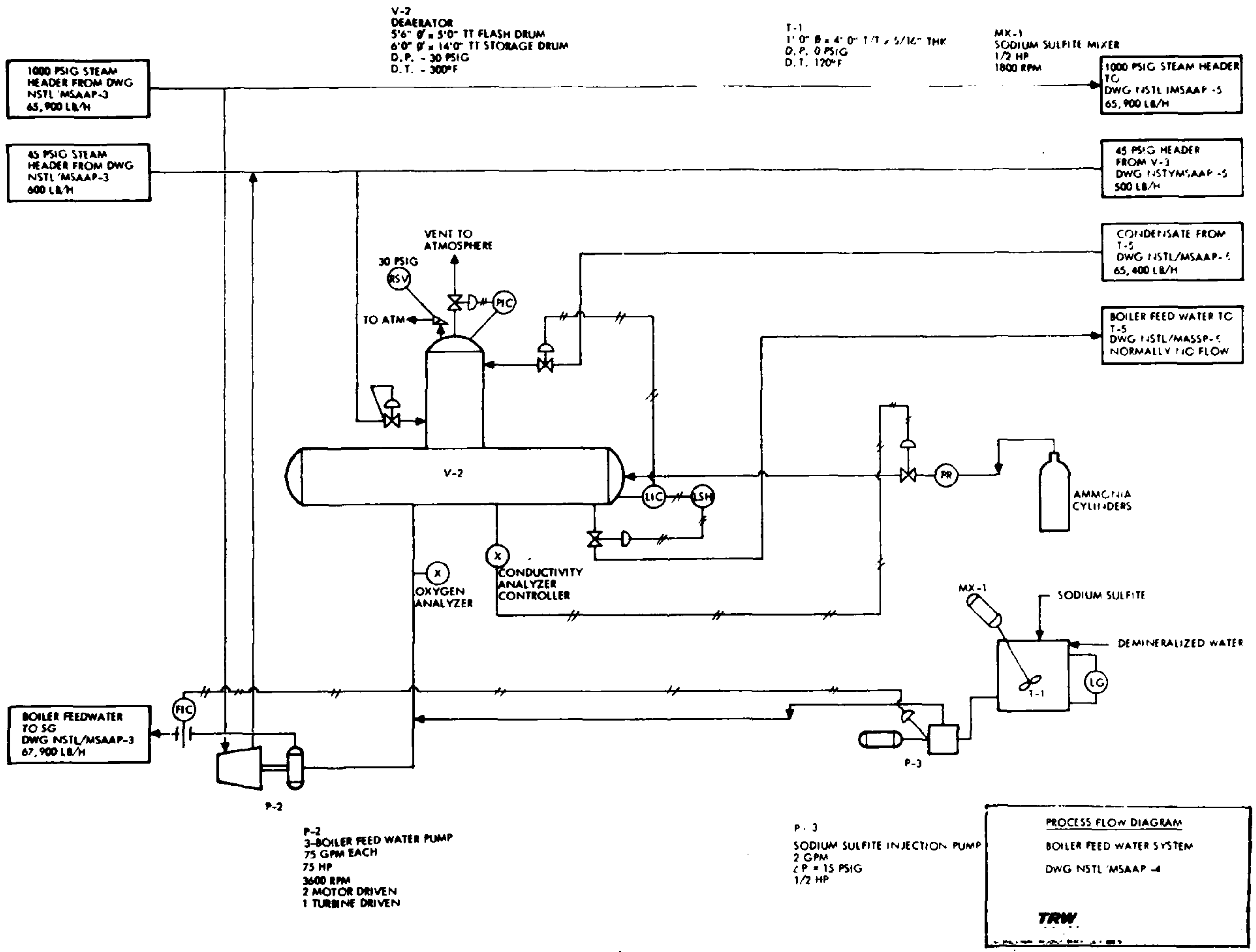

Figure 14. Process Flow Diagram - Boiler Feed Water System

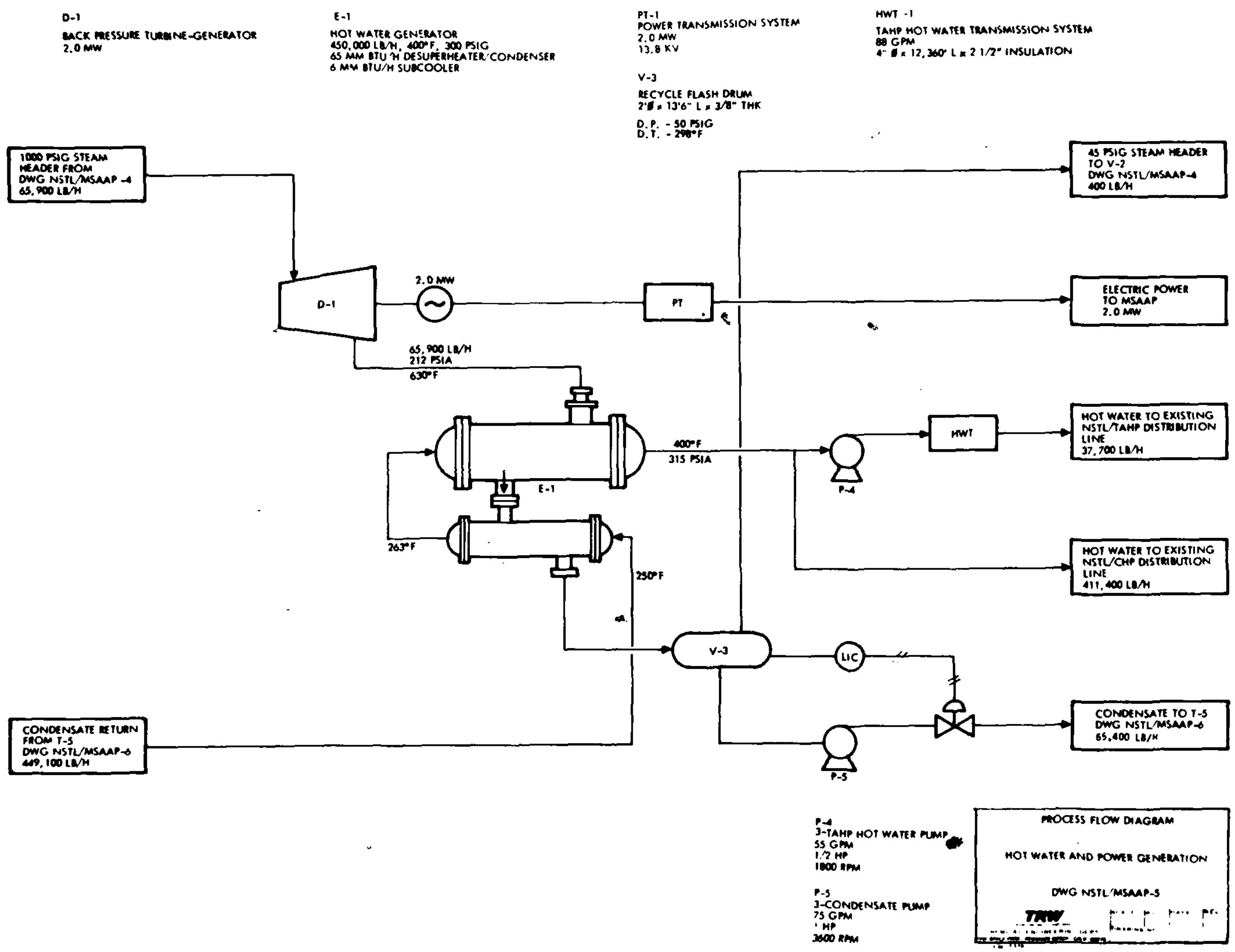

Figure 15. Process Flow Diagram - Hot Water and Power Generation

condensate to the deaerator by the condensate return pump (P-4A-C) using two pumps with one as a spare. The pumps are designed for 1000 GPM (227 m^3/hr) each with a discharge pressure of 305 psig (2.20 MPa). The process flow diagram for the water treating and condensate storage is shown in Figure 16 (Dwg NSTL/MSAAP-6).

During daytime operation, 2.0 MW of electric power is generated by the turbine-generator (D-1). The power generated is transmitted to the existing substation located over half a mile (0.8 km) south of the proposed plant site across the canal. A 1351 MCM Al conductor is installed above ground on 45 foot poles (13.72 m) at an average of 23 poles/mile (14.37 poles/km). To allow for 80 feet (24.38 m) clearance over the 200 feet (60.96 m) span canal, a steel tower 100 feet (30.48 m) high is installed at each bank. A new feeder system is installed with a distribution voltage of 13,800 volts. From the feeder at the substation, the 2.0 MW of electric power is transmitted to MSAAP at a distance of slightly over 2.0 miles (3.2 km). During turndown rate, less than one MW of power is transmitted to the MSAAP.

A list of the major process equipment required for the NSTL/MSAAP facility is included in Appendix H. The equipment numbers correspond to those in the process flow diagrams. The equipment list includes descriptions and installed equipment cost. Cost escalation from dated literature sources is based on the Marshall and Swift Cost Index. Sources of equipment costs from suppliers are also shown in Appendix H.

The two wood fired systems shown in Figures 6 and 12 were both designed primarily to supply the NSTL hot water requirement. A comparison of the operating parameters of these systems is presented in Table 20. Although both systems require the same annual energy consumption, system B supplies 2 MW of electric power in addition to the NSTL hot water requirement. System B is a more efficient energy utilization design than System A. In terms of the amount of heat energy fed to the plant that is converted to a useful energy product, System B produces 5.86 MM Btu/ton (1.89×10^{-3} w/kg) compared to 4.99 MM Btu/ton (1.61×10^{-3} w/kg) for System A.

MSAAP Steam Plant

The wood fired steam plant will provide saturated steam to the MSAAP facilities at 130 psig (1 MPa). Table 21 presents a breakdown of the steam requirements for each of the MSAAP buildings. For each facility a 10% safety factor is included and a line loss of 5% due to condensation during transmission is added to the total requirements. This results in an overall maximum steam demand of 152,230 lb/hr (69,050 kg/hr). Four waste heat boilers provided with the power plant diesel generators each provide 5,500 lb/hr (2,495 kg/hr) steam or a total of 22,000 lb/hr (9,979 kg/hr) steam at maximum capacity. This results in a wood fired steam generating requirement of about 130,000 lb/hr (58,967 kg/hr). Table 22 also indicates which facilities will collect and return condensate to the boiler system. It is assumed that about 85% of this collected condensate will be returned to the system with the remainder being lost as flashed steam to the atmosphere or sewered condensate. Other steam requirements not included in Table 21 are for water heating at the deaerator and steam for turbine drivers on boiler feedwater and condensate pumps.

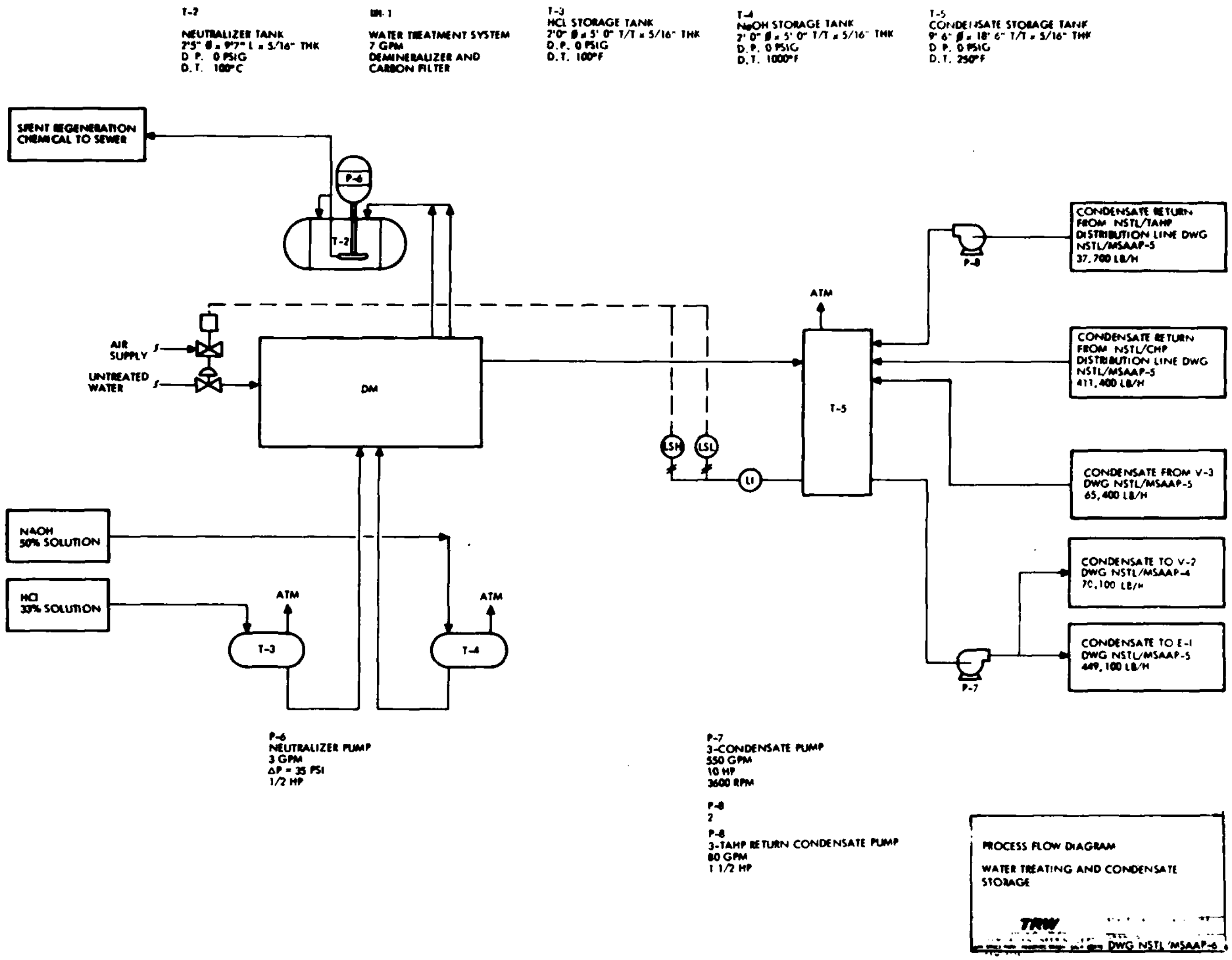

Figure 16. Process Flow Diagram - Water Treating and Condensate Storage

Table 20. Operating Parameters for the NSTL Hot Water Generator and the NSTL/MSAAP Hot Water and 2.0 MW Power Plant

	A NSTL		B NSTL/MSAAP	
Boiler Duty[a], Btu/H (Mw)	81,729,258	(24)	81,212,632	(24)
[Turndown][b] (Mw)	[37,842,771]	(11)	[37,206,907]	(11)
Steam				
lb/H (kg/hr)	82,118	(32,248)	65,912	(29,879)
	[38,000]	(17,236)	[30,196]	(13,697)
Pressure, psia (MPa)	330	(2.27)	1015	(7)
Temperature, °F (°C)	426	(219)	905	(485)
Efficiency, %	55	55	65	65
Fuel[c]				
TPH (kg/hr)	13.38	(12,138)	13.30	(12,065)
	[6.20)	(5,624)	[6.09]	(5,525)
Ave. TPH (kg/hr)	8.45	(7,665)	8.35	(7,575)
TPY (10^3 kg)	74,000	(67,131)	73,100	(66,315)
Hot Water				
lb/H (kg/hr)	449,150	(203,730)	449,150	(203,730)
	[207,957]	(94,327)	[207,957]	(94,327)
Pressure, psia (MPa)	315	(2.17)	315	(2.17)
Temperature, °F (°C)	400	(205)	400	(205)
Duty, Btu/H (Mw)	66,770,552	(19.5)	70,287,679	(20.6)
Power				
Mw	–		2.2	
			[.9]	

a 25% in excess of hot water flow rate, 68.08% boiler efficiency 11 hours/working day, 250 working days per year, 2750 hours/year.

b 13 hours/working day, 24 hours/non-working day, 115 non-working days/year, 6010 hours/year.

c Mostly southern pine, 90% moisture content dry basis, 4484 Btu/lb (wet), 3" x 3" x 3" nominal fuel feed size.

Table 21. MSAAP Steam Requirements

Buildings	Steam Demand[1] Process, lb/Hr	Building Heat, lb/Hr	Condensate Returned
Projectile Metal Parts	25,300	47,300	Yes
Cargo Metal Parts	29,700	5,500	Yes
Lab Facility	11,000	4,400	No
Power Plant	-	2,750	Yes
Waste Treatment Plant	5,500	7,040	Yes
Central Receiving Warehouse	-	7,040	Yes
Central Flammable Storage	-	990	No
Support Building	-	4,950	Yes
Totals(1)	71,500	73,480	
5% Line Loss	3,575	3,674	
Total Steam Generation	75,075	77,154	
Condensate Collected	60,500	67,540	
Condensate Returned(2)	51,425	57,410	

Notes:

1) lb/hr x .4536 = kg/hr
2) Includes 10% safety factor.
3) Assumes return of 85% of collected condensate.
4) Total plant capacity requirements = 75,075 + 77,154 = 152,229 lb/hr.

For the purposes of cost estimation and economic analysis a 1983 construction date and a 1985 start-up date are assumed. Two operational modes are considered:

- Mobilization mode where the plant operates at the design rates presented in Table 21 on a schedule of 24 hours per day, 5 days per week for 52 weeks per year. This results in 6240 operating hours per year at full rate.

- Peacetime mode where the plant operates at one-half the design rates presented in Table 21 on a schedule of 11 hours per day, 5 days per week, for 52 weeks per year, resulting in 2860 operating hours per year at half capacity.

Table 22. MSAAP Steam Balance

130 psig Steam	Generation, lb/hr*	Usage, lb/hr*
Diesel Waste Heat Boilers	21,754	-
Wood Fired Steam Generators	131,803	-
Process Steam	-	71,500
Building Heat	-	73,480
BFW Pump Turbines	-	1,030
Condensate Pump Turbine	-	235
Line Losses	-	7,312
Total	153,557	153,557
20 psig Steam		
Blowdown Drums	183	-
BFW Pump Turbines	1,030	-
Condensate Pump Turbines	235	-
Condensate Flash Drums	12,804	-
Deaerator	-	14,252
Total	14,252	14,252

* 1 kg = 2.2 lbs

The system layout will consist of four equal sized wood-fired steam generators with a common wood fuel feed system and boiler feedwater system. Spare equipment will be provided, where necessary, to assure a reliable and uninterrupted plant operation.

The wood fuel feed for the system will be mostly southern pine supplied from nearby NSTL forest lands or nearby paper mills on a contract basis. The wood will be a nominal 3" x 3" x 3" size with a maximum allowable oversize material of 20% consisting of material 1 foot in diameter by 3 feet long (.30-.91 m). The maximum allowable fines material (1/4" or less) will be 50%. The wood fuel will have a 90% moisture content on a dry basis or a 47.3% moisture content on a wet basis. The heating value of the wood on a dry basis is 8520 Btu/lb (19.8 x 10^6 J/kg) on a dry basis and 4484 Btu/lb (10.42 x 10^6 J/kg) on a wet basis. The expected boiler efficiency for a wood fuel of this type is 68% on the basis of the wet wood feed.

Drawing MSAAP-1 (Figure 17) represents the steam system heat and material balance. The drawing indicates pertinent process information such as steam and condensate flow rates, operating pressures and temperatures, and the enthalpy of individual streams. A total steam generation of 153,557 lb/hr (69,652 kg/hr) is required to meet the process and building heat demands plus line losses and the requirements of the steam turbine drivers for the boiler feedwater and condensate pumps. During normal operations the requirements for low pressure steam are met by flashing high pressure condensate and steam turbines exhausting into the low pressure header. All of the low pressure steam is used at the deaerator for boiler feedwater preheating with the excess being vented to the atmosphere through the deaerator. Table 22 (page 77) summarizes the accounting of the high and low pressure steam.

Water is lost from the system at the blowdown drum, line loss flash drum, deaerator vent, unreturned condensate from steam users, and flashed condensate at the condensate storage tank. These losses are made up by the addition of fresh demineralized water. Table 23 below summarizes the system water balance.

Table 23. MSAAP Water Balance

Source	Losses, lb/hr*	Make-up, lb/hr*
Line Loss Flash Drum (steam)	1,113	-
Line Loss Flash Drum (condensate)	6,199	-
Unreturned Condensate	16,940	-
Blowdown (condensate)	1,535	-
Deaerator Vent (steam)	1,912	-
Condensate storage vent (steam)	5,762	-
Make-up DMW	-	33,461
Total	33,461	33,461

* 1 kg = 2.2 lbs

The MSAAP Biomass Steam Plant is divided into six functional systems similarly to the two NSTL Biomass Plants. Process flow diagrams of these sections appear in Figures 18 through 23 (MSAAP-2 through 7). Wood fuel feed for the steam generators are unloaded from trailers and stored in a front end wood handling system similar to the system described previously. Sized wood chips are fed to four wood-fired steam generators in the

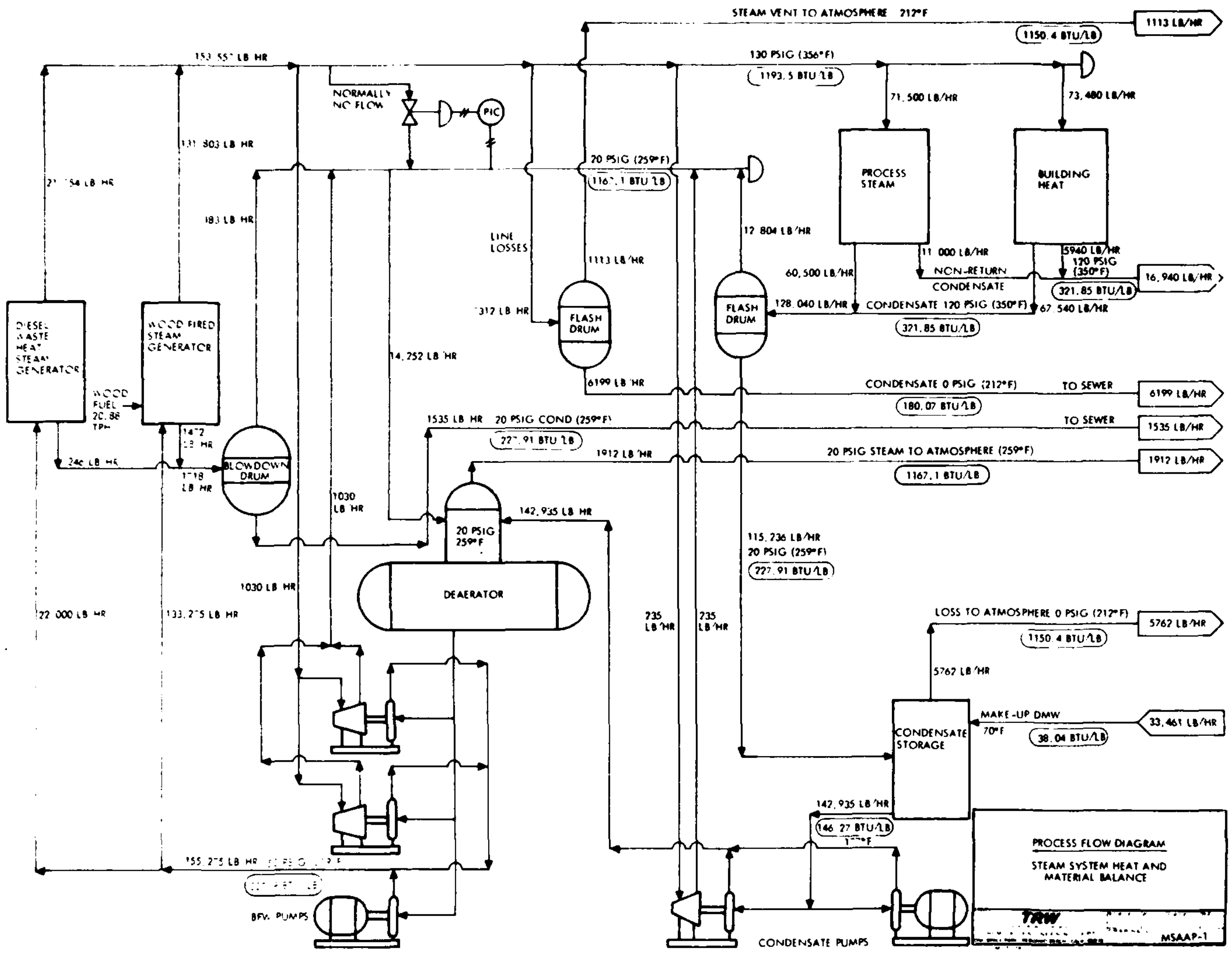

Figure 17. Process Flow Diagram - Steam System Heat and Material Balance

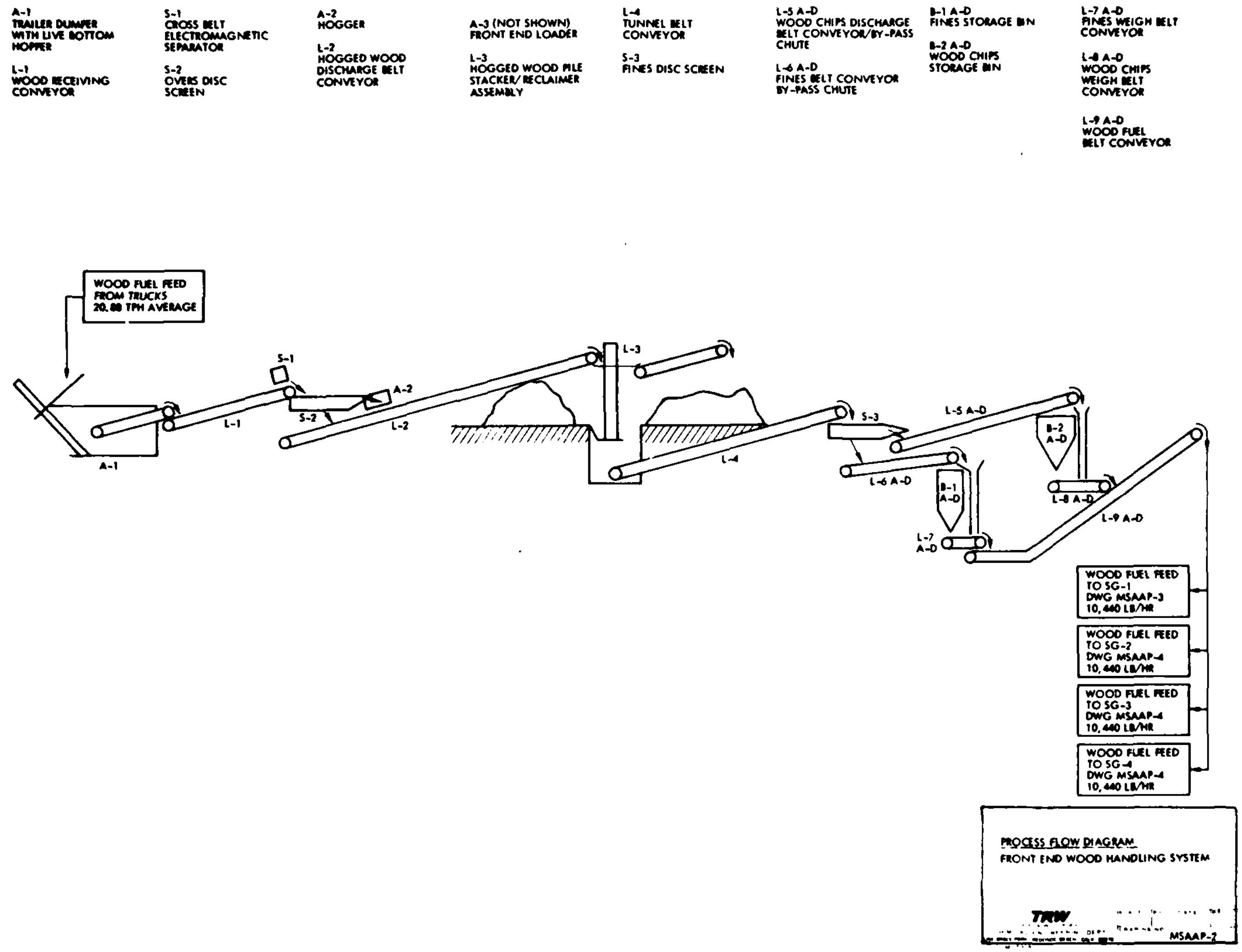

Figure 18. **Process Flow Diagram - Front End Wood Handling System**

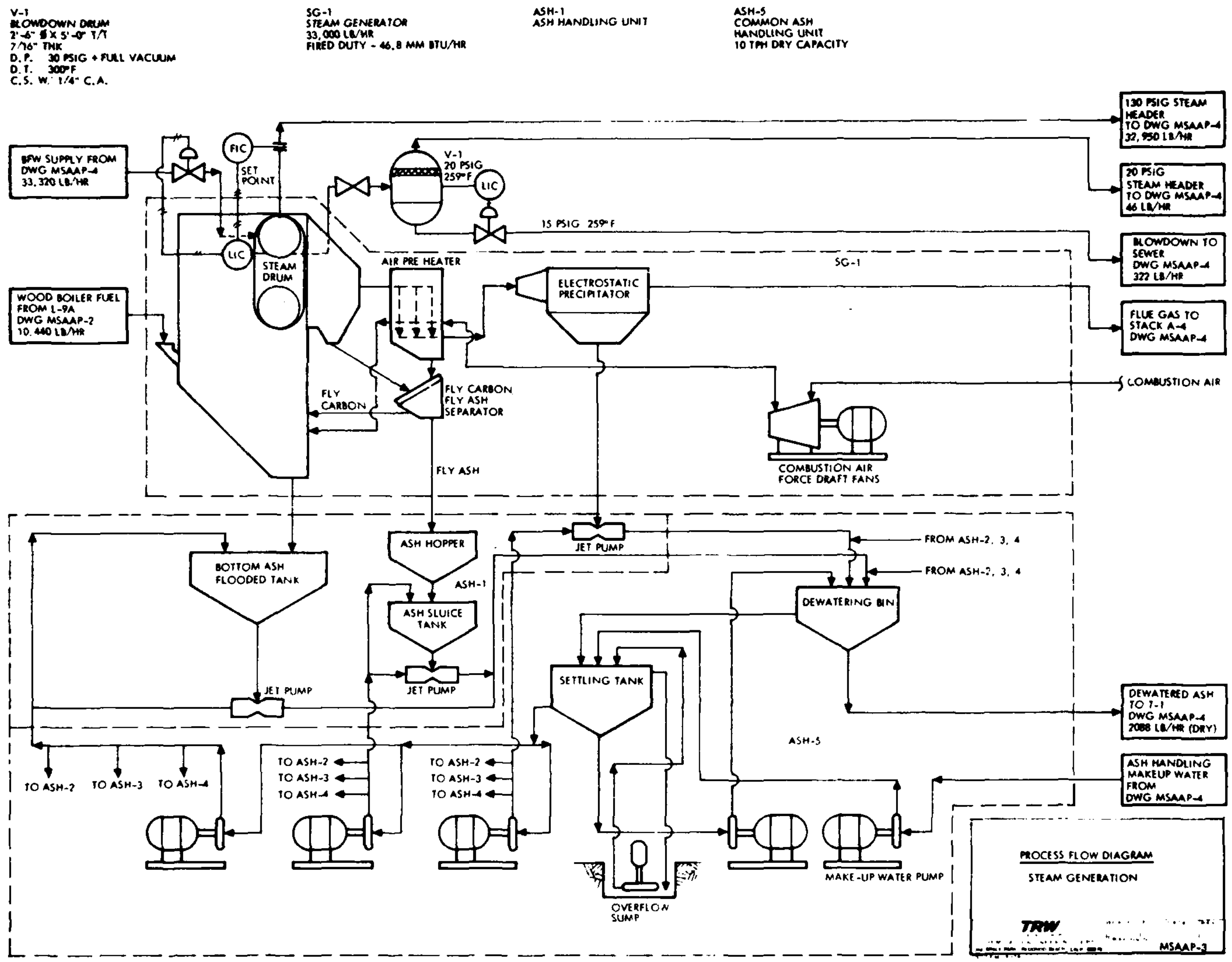

Figure 19. Process Flow Diagram - Steam Generation

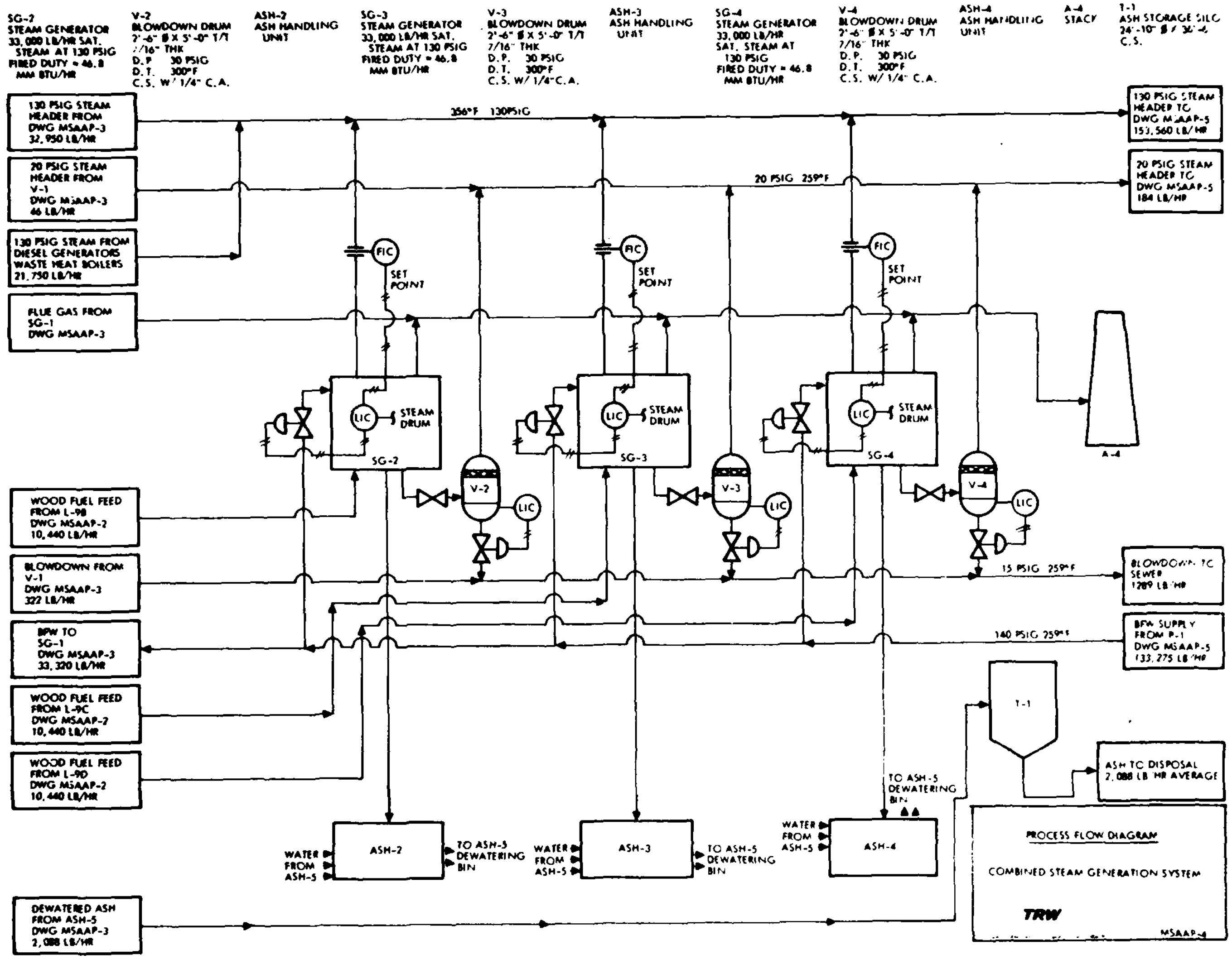

Figure 20. **Process Flow Diagram - Combined Steam Generation System**

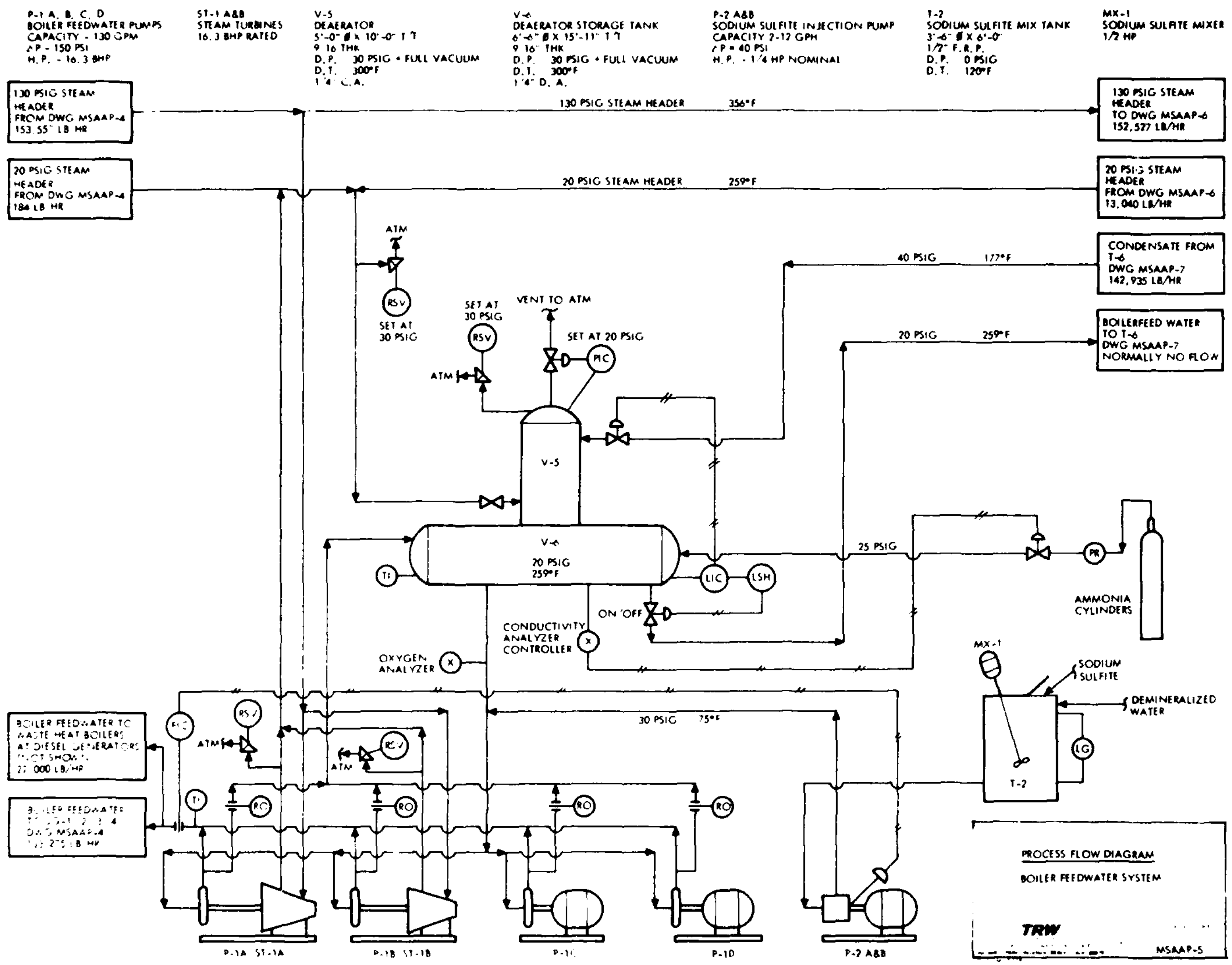

Figure 21. Process Flow Diagram - Boiler Feedwater System

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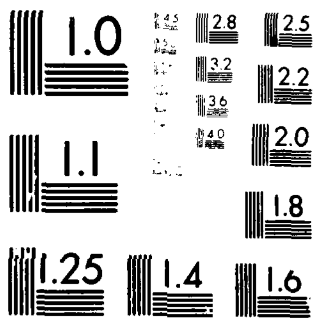

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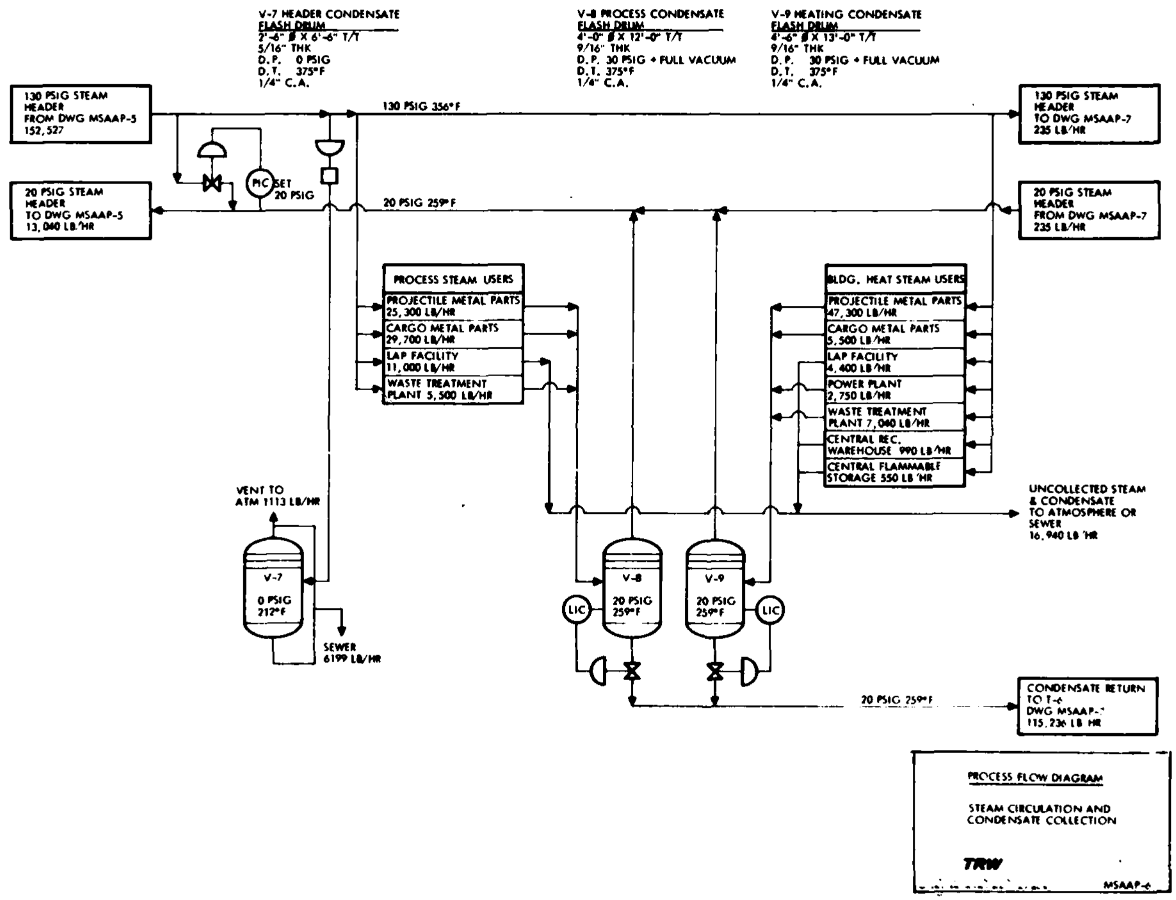

Figure 22. **Process Flow Diagram - Steam Circulation and Condensate Collection**

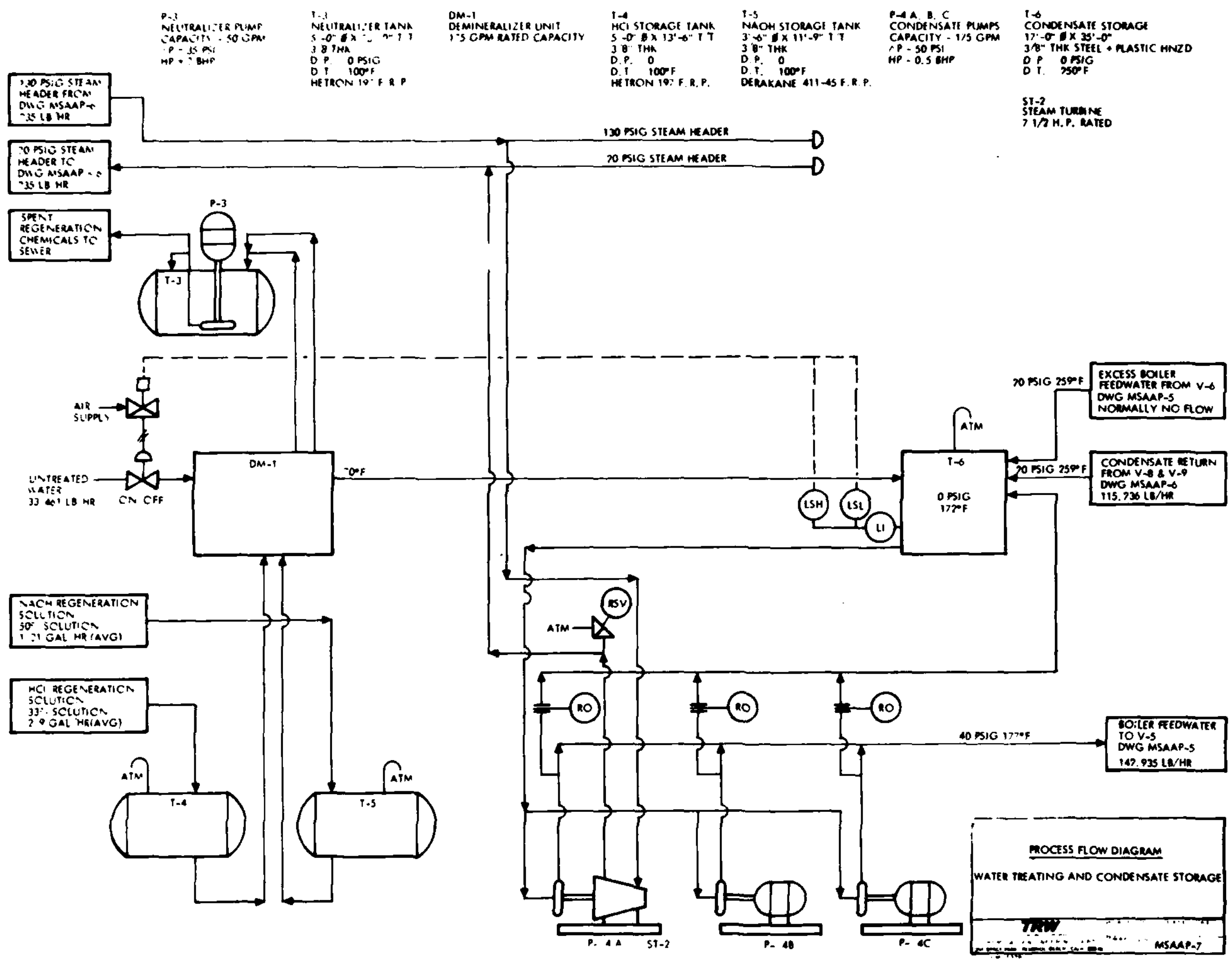

Figure 23. **Process Flow Diagram - Water Treating and Condensate Storage**

steam generation system. The feedwater to each boiler is received from a common header and fed to the steam drums at 259°F (126°C) and about 150 psig (1.14 MPa). Each boiler has an ash removal system consisting of a bottom ash flooded tank, ash hopper, ash sluice tank and several jet pumps for slurry service. Each system is connected to a common system for ash dewatering and removal. The boiler feedwater system provides deaerated treated water to the four boilers.

Figure 22 shows the circulation of steam to the process and heating users and the collection of condensate for return to the boilers. A letdown valve in the 130 psig (1.0 MPa) steam header provides steam to the 20 psig (0.24 MPa) steam header. Line losses in the 130 psig (1.0 MPa) steam header are assumed to be 5% of the steam flow. The condensate in the header system will be discharged at steam traps in the piping low points and collected in a common flash drum (V-7) where the steam vents to the atmosphere and the condensate is sent to the sewer.

The condensate which is collected from the process users at 120 psig (.93 MPa) and 350°F (177°C) is flashed to 20 psig (0.24 MPa) at the flash drum V-8. The flashed steam enters the 20 psig (0.24 MPa) steam system and the condensate at 259°F (126°C) is sent to condensate storage. A level controller on V-8 maintains a ten minute holdup of condensate by operating a control valve on the condensate discharge line. A similar flash drum system (V-9) is provided for the condensate returned from the building heat steam users. It is assumed that the uncollected condensate from both the process and heating steam users is lost to the sewer or the atmosphere at the user locations.

The water treating and condensate storage system consists of demineralizer unit (DM-1) designed to provide high quality makeup water to the condensate storage tank.

More information about the operation of the systems in the MSAAP Biomass Steam Plant and a list of the required major equipment, equipment description and cost are included in Appendix H. It should be noted that the installed equipment costs for the front end wood handling equipment, all of which appears on drawing MSAAP-2 (Figure 18), are total plant investment costs quoted by an equipment supplier. These costs, which are totalled separately from the other equipment costs, represent the total installed costs including contractors, overheads and profits, engineering and design, and contingency.

Economics of NSTL and MSAAP Energy Wood Plants

Presented in the following tables are the capital and operating cost summaries of the three energy wood plants described previously: The NSTL Hot Water Generator, The NSTL/MSAAP Hot Water and Power Plant, and The MSAAP Steam Plant.

The total capital requirement for each system is 11% higher than the total plant investment to include a one percent construction bond and 10% capital escalation to the midpoint of the last construction year. The total plant investment represents the depreciable invested capital and is the sum of the equipment costs, offsites, contractors overhead and profits, engineering and design, and contingency plus the total plant

investment (escalated to 1983 dollars) for the front end wood handling system. The total plant investment for the energy conversion plant is based on the sum of the capital installed equipment presented in Appendix H for each system exclusive of the front end wood handling equipment. The offsites costs estimated at 10% of the capital equipment costs, represents the cost for building, control rooms, laboratories, maintenance facilities, raw water storage and pumping facilities and waste treatment facilities. The contractors overheads and profits are estimated at 22% of the sum of the equipment and offsite costs. Engineering and design is estimated at 10% of the sum of the equipment and offsite costs. A contingency is applied which is 15% of the sum of the equipment, offsites, contractors overhead and profit and engineering and design costs. The total plant investment for the wood handling system in each system is an equipment supplier estimate to procure, install, and startup the wood handling system.

As shown in Table 24, the capital requirement for the NSTL energy wood HTHW plant is $11.02 million and includes a $3.3 million wood handling system. The capital requirement summary for the NSTL/MSAAP HTHW and

Table 24. NSTL Hot Water Generator Capital Requirement (in thousands of dollars) [1983$]

Total Plant Investment, Front End		$ 3,305
Total Plant Investment, Energy Conversion		
A. Capital Equipment Installed Cost	$ 3,967	
B. Offsites 10% of (A)	397	
C. Contractors Overhead and Profits 22% of (A + B)	960	
D. Engineering, Design, and Site Adaptation 10% of (A + B)	436	
E. Contingency 15% of (A + B + C + D)	865	
		6,625
Total Plant Investment (1983$)		$ 9,930
Bond (1%)		99
Escalation To midpoint of construction (10%/year)		993
Total Capital Requirement (1983$)		$11,022

electric power plant, $14.4 million, is shown in Table 25. At $14.4 million, this system, which requires approximately the same amount of energy wood feed, costs an extra $3.4 million in electric power generation and power transmission equipment for 2.2 MW.

Table 25. NSTL/MSAAP Hot Water and Power Plant Capital Requirement (in thousands of dollars)[1983$]

Total Plant Investment, Front End Section		$ 3,305
Total Plant Investment, Energy Conversion		
A. Capital Equipment Installed Cost	$5,776	
B. Offsites @ 10% installed cost	578	
C. Contractor's Overhead and Profits @ 22% (A + B)	1,398	
D. Engineering, Design, and Site Adaptation @ 10% (A + B)	635	
E. Contingency @ 15% (A + B + C + D)	1,258	
		9,644
Total Plant Investment (1983$)		12,949
Bond (1%)		129
Escalation To midpoint of construction (10%/year)		1,295
Total Capital Requirement (1983$)		$14,373

The capital cost summary for the MSAAP energy wood steam plant is presented in Table 26. As shown, the $23.1 million includes a total plant investment cost of $20.8 million. This plant was designed to the equivalent specifications of a coal-fired steam plant having an estimated plant investment cost of $29.1 million (Reference 27) and therefore represents a cost avoidance of $8.3 million.

Table 26. MSAAP Capital Requirement (in thousands of dollars) [1983$]

Total Plant Investment, Front End		$ 5,611
Total Plant Investment, Energy Conversion		
A. Capital Equipment Installed Cost	$9,105	
B. Offsites 10% of (A)	910	
C. Contractor's Overhead and Profits 22% of (A + B)	2,204	
D. Engineering, Design and Site Adaptation 10% of (A + B)	1,002	
E. Contingency 15% of (A + B + C + D)	1,983	
		15,204
Total Plant Investment (1983$)		20,815
Bond (1%)		208
Escalation To midpoint of construction (10%/year)		2,082
Total Capital Requirement (1983$)		$23,105

The annual operating costs for the three energy wood systems are presented in Tables 27 through 29. The sources of the costs used in this analysis are technical literature, equipment suppliers, and internal (TRW) costing data. Since a 1983 construction date with a two year construction period is assumed, the operating costs presented are escalated to 1985 dollars.

The cost of wood fuel for the systems is based on an estimate by International Paper Company (Appendix F) which quoted a price of $18.50 per ton ($.02/kg) for 1980 with an annualescalation of 8 to 10% per year. This results in a 1985 price of $27.18 per ton ($.03/kg). The only utility costs shown are for electric power and raw water. Power costs are calculated

Table 27. NSTL Hot Water Generator Annual Operating Cost (in thousands of dollars) [1985$]

Fuel		
Wood (74,057 tons per year @ $27.18/ton)		$2,012.87
Utilities		
Power (.9 x 10^6 kwh/yr @ $.065/kwh)	$58.74	
Water (15.6 x 10^6 gals/yr)	8.76	
		67.50
Chemicals		
HCl @ $85/ton	.58	
NaOH @ $222/ton	.81	
Na_2SO_3 @ $13.25/100 lbs	2.44	
Ammonia @ $.125/lb	1.09	
		4.92
Operating Labor		
25,856 manhours per year @ $13.65/hr (Includes 30% burden)		352.93
Administration and General Overhead		
Supervision and Overhead @ 50% Total Labor		320.61
Operating Materials		
30% Operating Labor		105.88
Maintenance		
3% Plant Investment Adjusted for Inflation 60% Labor, 40% Materials		297.88
Depreciation		
20 yr straight line 5% Total Plant Investment		496.50
Ash Disposal		
7221 tons per year @ $2.00/ton		14.44
Total Gross Annual Operating Cost (1985$)		$3,673.53
By-Product Credits		
Merchantable Wood (1985) minus Site Preparation and Planting		422.00
Total Net Annual Operating Cost (1985$)		$3,251.53

Table 28. NSTL/MSAAP Hot Water and Power Plant Annual Operating Cost (in thousands of dollars)[1985$]

Fuel		$1,988.92
Wood (73,176 tons per year @ $27.18)		
Utilities		
Power (1.3 x 10^6 kwh/hr @ $.065/kwh)	85.75	
Water (5.26 x 10^6 gal/yr @ $.50/1000 gal)	2.63	
		88.38
Chemicals		
HCl @ $85/ton	1.08	
NaOH @ $222/ton	1.50	
Na_2SO_3 @ $13.25/100 lbs	2.34	
Ammonia @ $250./ton	1.05	
		5.97
Operating Labor		
25,856 manhours per year @ $13.65/hr (Includes 30% burden)		352.93
Administration and General Overhead		
Supervision and Overheads @ 50% Total Labor		356.40
Operating Materials		
30% Operating Labor		105.88
Maintenance		
3% Plant Investment Adjusted for Inflation 60% Labor, 40% Materials		444.84
Depreciation		
20 yr straight line 5% Total Plant Investment		647.45
Ash Disposal		
6,934 tons per year @ $2.00/ton		13.87
Total Gross Annual Operating Cost		$4,004.64
By-Product Credit		
Surplus Electric Power (6,107,659 kw @ $.065/kw)		397.00
Merchantable Wood minus Site Preparation and Planting		422.00
Total Net Annual Operating Cost (1985$)		$3,185.64

Table 29. MSAAP Annual Operating Cost
(in thousands of dollars)[1985$]

	Peacetime	Mobilization
Fuel Wood	$ 811.2	$3,539.6
Utilities		
Power	48.8	224.5
Water	3.0	13.6
Chemicals		
HCl	1.7	7.6
NaOH	2.4	10.4
Na_2SO_3	1.5	3.3
Ammonia	0.4	0.8
Operating Labor	195.2	567.8
Supervision and Overheads	312.1	498.4
Operating Materials	58.8	170.3
Plant Maintenance	714.9	714.9
Depreciation	1,040.8	1,040.8
Ash Disposal	4.3	18.6
Total Gross Annual Operating Cost	$3,195.1	$6,810.6
By-Product Credits		
Merchantable Wood minus Site Preparation and Planting	422.0	422.0
Total Net Annual Operating Cost (1985$)	$2,773.1	$6,388.6

assuming a 1985 price of $.065/kw. The raw water usage is to provide makeup water for the boiler feedwater and ash handling system. A 1985 cost of $.05 per 1000 gallons ($.132/m^3) was assumed.

Small quantities of several chemicals are required for boiler feedwater treating and regeneration of the demineralizer unit. Hydrochloric acid (33% solution) costs for demineralizer regeneration are estimated at $85 per ton ($.09/kg). Caustic soda (50% solution), also required for the demineralizer, is estimated to cost $222 per ton ($.24/kg) in 1985. Sodium

sulfite is used as an oxygen scavenger in the boiler feedwater. It is estimated to cost $13.25 per 100 pounds ($.29/kg) in 1985. Ammonia, used for boiler feedwater pH control is estimated to cost $250 per ton ($.28/kg) in 1985.

The labor cost is estimated at $13.65 per man-hour which is based on a present $7/hr escalated to 1985 at 7%/yr and includes a labor burden of 30%. Plant maintenance is estimated at 3% of the total plant investment escalated to 1985. This cost is broken down as 60% labor and 40% materials. Operating materials are estimated at 30% of the operating labor cost. The cost for supervision and overheads are estimated at 50% of the total operating and maintenance labor.

Although dewatered ash may be a potentially attractive forest fertilizer, ash represents a disposal problem for the operating plant. A cost of $2 per ton ($.24/kg) is therefore included in the plant operating expenses.

The sum of the above items represents the annual non-amoritized operating cost to which a charge for depreciating the invested capital is added to obtain the gross annual operating cost. The depreciation is taken at 20 year straight line or 5% of the total plant investment.

The net annual operating cost is obtained by crediting each system with the appropriate by-product values. All three systems are credited with the value of the merchantable timber which will be harvested under the forest management plan to convert the existing NSTL forest to an operating energy plantation as discussed previously. The merchantable bole is assumed to be 24% of the volume harvested from the natural NSTL forest. The credit is $95.21 per ton ($.10/kg). Each operating plant is also debited $83,300 annually for site preparation and planting. The NSTL/MSAAP plant, Table 28, produces electric power. A by-product credit of $.065/kw is included.

In Table 29 the operating cost summary for the MSAAP wood-fired steam plant is presented. Since the costs for operation under peacetime and mobilization modes are quite different, both are presented in the table. The basis for design, discussed previously, defines the peacetime mode as operating at one-half capacity, 11 hours per day, 5 days per week for 52 weeks per year. This is equivalent to operating at one-half capacity for 2860 hours per year which is the basis for the peacetime mode operating costs. Mobilization mode is defined as operating at full capacity, 24 hours per day, 5 days per week for 52 weeks per year which is equivalent to full capacity operation for 6,240 hours per year. The annual fuel consumption is 29,844 tons (27.074×10^6 kg) and 130,229 tons (118.141×10^6 kg) under peacetime and mobilization mode, respectively. Power consumption is estimated at 765,500 kw-hr/yr for peacetime operation and 3,404,500 kw-hr/yr for the mobilization mode of operation. Peacetime consumption of raw water is estimated at 6.1 million gallons (23,091 m^3) per year and 27.2 million gallons (102,950 m^3) per year under mobilization. Hydrocholoric acid requirements are 20.3 tons (18.4×10^3 kg) per year at peacetime operation and 89 tons (80.7×10^3 kg) per year at mobilization. Caustic soda requirements are estimated at 10.8 tons (9.8×10^3 kg) per year at

peacetime and 47 tons (42.6 x 10^3 kg) per year at mobilization. Sodium sulfite annual requirements are estimated at 11,440 lbs (5,189 kg) and 24,960 lbs (11,322 kg) at peacetime and mobilization rates, respectively. Ammonia requirements are 2860 lbs/year (1297 kg/hr) at peacetime and 6240 lbs/year (2830 kg/yr) at mobilization. Operating labor is based on 14,300 man-hours per year under peacetime operation and 41,600 man-hours per year under mobilization mode. The disposal requirements, based on an ash which is 30 to 50% moisture, are 2130 tons (1.9 x 10^6 kg) per year at peacetime and 9310 tons (8.4 x 10^6 kg) per year at mobilization.

Based on the steam generated, the cost is $18.18/1000 lbs ($.04/kg) for peacetime operation and $8.57/1000 lbs ($.02/kg) for mobilization. The same costs, when translated into terms of heat generated, are $18.80 per million Btu ($17.81/10^9 J) for peacetime operation and $8.86 per million Btu ($8.39/10^9 J) for mobilization.

The large differences in cost between the peacetime and mobilization modes are due to the fact that the plant is greatly oversized for peacetime operation. Fixed charges such as plant maintenance and depreciation which are calculated as a percentage of the capital investment are essentially the same for the two operational modes. These charges result in a heavy cost burden during peacetime operation when approximately one-half of the equipment is idle or operating at less than optimum capacity.

To determine the return on investment (ROI) of the biomass NSTL Hot Water Generator Plant and the NSTL/MSAAP Hot Water and Power Plant, the operating costs over a 20 year plant life were calculated. These costs are compared to the annual operating cost of the existing fossil fuel HTHW plants in Table 30. The ROI is defined as the interest rate at which the sum of the discounted annual savings equals the total plant investment. At a total plant investment of $9,930,000, the calculated ROI of the biomass NSTL Hot Water Generator Plant is 22.8%.

The total gross annual operating cost for the NSTL/MSAAP Hot Water Generator and Power Plant (Table 28) minus the cost of wood fuel and the depreciated capital investment and plus the constant dollar value of the electric power by-product is $217,000 lower than the value for the NSTL Hot Water Generator Plant. Therefore, the annual savings compared to the fossil fuel HTHW plant is $217,000 higher than the values shown in the right column of Table 30. At a total plant investment of $12,948,000 the calculated ROI of the biomass NSTL/MSAAP Hot Water and Power Plant is 20.0%.

Shown in Table 31 is a comparison of the operating cost of a 10,000 TPY (9 x 10^6 kg) coal fired steam plant to the biomass MSAAP steam plant. At a cost avoidance of $8,330,000 (a total plant investment of $20,815,000) the calculated ROI for the biomass plant is 6.8%. Without cost avoidance, the calculated ROI of the biomass plant is 3.5%

Table 30. Comparison of Operating Costs of NSTL Fossil Fuel and Biomass Hot HTHW Plants (in thousands of dollars)

Year	Natural Gas Fuel Cost [a]	Constant $ Operating Cost [b]	CHP and TAHP Operating Cost	Wood Fuel Cost [c]	Constant $ Operating Cost [d]	Merchantable Wood Credit [e]	Constant $ Site Preparation Cost	NSTL Hot Water Generator Operating Cost	Savings
1 (1985)	2390 +	1363 =	3753	2013 +	1164 -	505 +	83.3 =	2755	998
2	2581		3944			571		2687	1257
3	2788		4151			619		2639	1512
4	3011		4374			676		2582	1792
5	3252		4615			733		2525	2090
6	3512		4875			790		2468	2407
7	3793		5156			847		2411	2745
8	4096		5459			904		2354	3105
9	4424		5787			943		2315	3472
10	4778		6141			1000		2258	3883
11	5160		6523			1047		2211	4312
12	5573		6936			1104		2154	4782
13	6018		7381			1152		2106	5275
14	6500		7863			1200		2058	5805
15	7020		8383			1257		2001	6382
16	7581		8944			1304		1954	6990
17	8188		9551			1352		1906	7645
18	8843		10206			1400		1858	8348
19	9550		10913			1447		1811	9102
20	10315		11678			1495		1763	9915

[a] Based on 395 x 10^6 CF (11 x 10^6 m^3) at 2.645/MCF ($.09/$m^3$) in 1980 with an inflation factor of 10% per year (1980 to 1985) plus an escalation factor of 8% per year from 1980 to 2005.

[b] Includes $76,000 utilities; $1,227,000 labor and $60,000 materials.

[c] Based on $27.18 per ton ($.03/kg) energy wood cost and 74,057 TPY (67.18 x 10^6 kg).

[d] From Table 27, total gross annual operating cost minus cost of wood fuel and depreciated capital investment.

[e] Based on $95.21 per ton ($.10/kg) merchantable wood value, 493 acres harvested per year (2 km^2) and estimated annual growth ranging from 1.82 (year 1) to 1.33 (year 25) cds/acre/year (450 to 379 cds/km^2/yr).

Table 31. Comparison of Operating Cost of MSAAP Fossil Fuel and Biomass Steam Plants (in thousands of dollars) at Peacetime Rates

Year	Fuel Cost[a]	Constant $ Operating Cost	Coal Plant Operating Cost	Wood Fuel Cost[b]	Constant $ Operating Cost[c]	Merchantable Wood Credit	Constant $ Site Preparation Cost	Biomass Operating Cost	Savings
1 (1985)	1156 +	1524 =	2680	811.2	+ 1343	- 505	+ 83.3 =	1735	947
2	1214		2738			571		1667	1071
3	1275		2779			619		1621	1160
4	1338		2862			676		1562	1300
5	1405		2928			733		1505	1423
6	1476		3000			790		1448	1552
7	1550		3074			847		1391	1683
8	1627		3151			940		1334	1817
9	1708		3232			943		1295	1937
10	1794		3318			1000		1238	2080
11	1883		3407			1047		1191	2216
12	1978		3502			1104		1134	2368
13	2076		3600			1152		1086	2514
14	2180		3704			1200		1038	2666
15	2289		3813			1257		981	2837
16	2404		3928			1304		934	2994
17	2524		4048			1352		886	3162
18	2650		4174			1400		838	3336
19	2783		4307			1447		791	3516
20	2922		4446			1495		743	3703

[a] Based on 10,000 TPY (9 x 10^6 kg) at $50/ton ($.055/kg) in 1979 with an inflation factor of 10% per year (1979 to 1985) plus an escalation factor of 5% per year (1979 to 2005).

[b] Based on $27.18 per ton ($.03/kg) energy wood cost and 29,844 TPY (27.074 x 10^6 kg).

[c] From Table 29 (peacetime), total gross annual operating cost minus cost of wood fuel and depreciated capital investment.

Environmental and Legal Aspects of NSTL/MSAAP Biomass Energy Conversion

Major questions involving the development of a biomass-to-energy operation and the feasibility of a biomass energy source concern the impact on the environment of the total operation and the legal aspects. The environmental impacts are initially those caused by the harvesting and land amelioration practices necessitated to insure a constant supply of energy wood such as harvest cutting mature stands of lunber, site drainage, single species stocking and pest control. However, the impact by the operation of the energy conversion unit must also be considered. The selected technology, direct combustion by wood fired spreader stoker furnaces, will result in flue gases which must be treated to remove particulates and any other environmentally unacceptable emmissions. Ash will also be generated as the wood is burned and this solid product must be disposed of in an environmentally sound manner.

The legal issues related to the operation of a biomass plant at NSTL/MSAAP involve the requirements for contracting to secure consistent long-term supplies of energy wood. There are also legal issues concerning the licensing requirements for operating a biomass plant. Finally there is the legal issue involving the releasing of government forest lands for production in order to insure additional supplies of energy wood.

The evaluation of these environmental and legal issues involving the operation of a NSTL/MSAAP biomass plant are discussed below.

Harvesting

TRW selected spreader stokers for the biomass-to-energy conversion systems for the NSTL/MSAAP applications. The source of the biomass supply for these plants was based on the harvesting and regenerative management of NSTL fee and buffer area forest. The environmental considerations of the biomass energy system are therefore the impacts of harvesting and energy plantation management on the land, water and wildlife; and the impact of emitting the products of wood combustion on the air, water, and land in the area.

An assessment by the Mississippi Air and Water Pollution Control Commission of silvicultural non-point source pollution has shown that in Mississippi, forest practices do not contribute significantly to non-point source pollution, although a few individual practices may be potential contributors to non-point source pollution by the production of sediment (Reference 28). Certain activities in the forest may temporarily disrupt or destroy soil cover. Such activities, while occurring once during a 25 year rotation, may expose the soil and make it vulnerable to erosion. Within a short time, however, ground cover is re-established. Some erosion, resulting in sedimentation, may occur during these infrequent short periods. Harvesting by clearcutting does produce soil disturbance which may temporarily result in some soil movement. The recovery period for such distrubances is from 2-3 years. Soil disturbance is caused by the use of heavy mechanical equipment such as rubber tire skidders, and heavy trucks (Reference 28).

In relation to water quality, thinning does not pose any problems. In such operations very little of the ground cover is disturbed and that which is disturbed heals within months. In an undisturbed, forested area, the capacity of the soil to accept rainwater is very high. Typically, heavy cutting of the forest will not affect this property of the soil unless the soil itself is disturbed. However, the removal of the overhead canopy during clearcutting will increase the annual runoff. The destruction of leaves and their transpiring surface area reduces the level of water intake necessary by vegetative roots. If the water seepage through the soil is too slow to accommodate this increased burden, then runoff and stream flow will increase. The litter cover and forest floor usually remain intact and will furnish some protection until a new canopy is established. Although soil erosion can result from all aspects of a harvest (roads, skid trails, and the cut surface or harvested area), roads skid trails and mechanical site preparation are the major sources of soil loss due to topsoil distrubance. The fact that the NSTL site already has a good road network will not only facilitate in-forest whole-tree chipping but will also minimize the need for new forest road construction. The proposed in-forest whole-tree chipping method causes less site disturbance than the traditional methods of harvesting. Topsoil disturbance should be kept to a minimum.

A study of the NSTL site revealed that due to heavy timber cutting in the past and losses sustained during Hurricane Camille in 1969, much of the land is carrying less than 50% of its capacity. With good land management practices such as fertilization and thinning, any erosion due to clearcutting should be offset by the soil stabilizing effect of more trees of greater quality in other parts of the forest.

Based on physical soil properties, soil wetness class, and annual precipitation, most of the NSTL area and most of the surrounding terrain is rated as having moderate to severe equipment limitations or restrictions. A rating of moderate indicates that logging is restricted from 1-3 months during the year; a severe rating indicates restriction for more than three months. These restrictions can be overcome by the use of specialized logging equipment such as oversized tires on skidders to assure good flotation during wet periods.

Removal of the forest cover permits direct solar radiation into any stream. This results in higher water temperatures and in greater daily fluctuation between maximum and minimum temperature. Clearcutting in a given area may result in temperatures greater than those which can be tolerated by the local fish. Because of the importance of shade, a buffer strip left adjacent to streams is effective in maintaining stream temperatures through a clearcut area (Reference 29). In addition, a buffer strip will prevent siltation and maintain bank stabilization.

There are two sources of wood that can increase currently harvested volumes. First, a virtually unused resource are tree-tops which without the use of in-forest chippers, are too costly to remove. Second, the deformed, rotten, diseased and undersirable trees can be removed and chipped to allow for the growth of an upgraded forest. The NSTL site may

have above average infection by fusiform rust. Fusiform rust kills some pine trees, makes the stand more susceptible to wind-throw. and reduces overall volume yield. These undesirable trees occupy valuable land space and compete for soil nutrients and water.

Forests remove definable amounts of nutrient materials from the soil each year. The rate of uptake depends on many factors, such as species of tree, age of stand, soil nutrient availability, and available moisture. In normal forest harvesting, residues are either allowed to decay on the forest floor or are piled and burned. In either case, most of the inorganic chemical content of the residues is returned to the soil. The degree of nutrient loss from a forested area after it has been clearcut is important for two reasons. For one thing, a heavy loss would contribute to an adverse water quality situation by resulting in an accelerated rate of eutrophication. In addition, future productivity of the forest site might also be impaired (Reference 29).

Complete tree utilization and short rotations will significantly reduce the available nutrient pool. In whole-tree chipping the entire tree is utilized, including the foliage which is left behind in traditional harvesting methods. However, since the foliage is the tissue with the highest nutrient concentration, particularly for nitrogen, phosphorus, and potassium, utilization of foliage can increase total nutrient removals by 100% over stem-only utilization. Such increases are greater when 25 year rotations are employed since the foliage is a larger portion of the phytomass in stands of this age.

In terms of mass, forest stands have a developmental period when rates of accumulation are high, followed by a period of maturity when accumulation is low and when productivity is devoted to maintenance of the accumulated mass. Data show that employing three 20-year rotations rather than a single 60-year rotation can increase yields by two-thirds (Reference 30). In summary, yield and nutrient removals are increased by shortening the rotation regardless of the utilization method employed.

The use of fertilizers to replace the nutrients that have been removed by whole tree harvesting operations is a recent forest management practice. The contribution of surface application of fertilizers as a source of pollution must be considered. Of the major nutrients, nitrogen and phosphorus are the most important from a depletion standpoint. Nitrogen depletion is greatest during the early decades of stand development when the canopy and actively absorbing root masses are developing. In nitrate form, nitrogen moves freely through the soil in solution. Most of the flatwoods soils are phosphorus deficient. Phosphorus is present in the soilplant system in organic and inorganic forms. The organic phosphorus is present in the forest floor and the soil organic matter. The remainder of the phosphorus is inorganic, and since the forest soils are acidic, the inorganic phosphorus will be relatively unavailable. Nitrogen and especially phosphorus will be applied as part of the site amelioration practice after clearcutting. Similar soils in the region

have shown dramatic increases in total above ground biomass yields after fertilization. Applications of fertilizer to forests is a recent management practice. The use of commercial fertilizer on forest land in Mississippi started in the 1950's and has been very limited in scope. The U.S. Forest Service applies small amounts to limited areas on an experimental basis. A few forest industry companies are also experimenting with its use in field plantings. Fertilization, therefore, is not considered to be a significant non-point source of pollution in Mississippi (Reference 28). However, data for long-term results of fertilizer application are not available.

In summary, proper forest management can mitigate or even eliminate many potentially adverse effects of harvesting. The sequence of activities required to establish, harvest, and regenerate a pine stand should be planned to minimize soil erosion and exposure. Although heavy equipment is required for complete-tree harvesting, if used with care, the overall environment can be protected.

Timber harvesting operations will result in various impacts on wildlife populations. Whether or not the impacts are beneficial is largely a matter of viewpoint. An activity that is detrimental to one species could conceivably be beneficial to another. For instance, the removal of tall trees would tend to improve the habitat of those species living on or near the ground. On the other hand, such an action would result in the elimination of habitat of those species which occupy the canopy.

The timing of timber harvests can seriously affect wildlife productivity. Cuttings are less apt to be disruptive if made from late summer to late winter. If made in April and May, timber cuttings may seriously curtail breeding activity of ground nesting birds. Since timber harvest practices have an immediate and long-term effect on wildlife, wildlife habitat management should be integrated with the kind, sequence, and arrangement of the timber harvest.

Forests provide many recreational opportunities: hunting, fishing, hiking, camping, picnicking. Recreationalists are apt to be very sensitive to the visible presence of timber harvesting operations. Even though the NSTL site is off limits to the general public, steps should still be taken to minimize the visual effects of timber harvesting.

Particulate Control

Particulate emissions from wood fired spreader stoker furnaces are the most visible, and, therefore, the most controlled, atmospheric pollutant. Particulates could be quite high if uncontrolled. In a biomass conversion process the primary particulates pollutants result from the entrainment of ash, sand, and unburned hydrocarbons and carbon in the combustion gases. The size of the particles can range from submicron "smoke" particles to pieces of wood or char 0.5 inch (0.013 m) or larger. The material is usually chemically stable as it enters the atmosphere.

Regulations covering particulate emissions are usually nonspecific regarding chemical and physical properties. Most are concerned only with the amount or concentration of particulate emissions. Emission regulations for wood-fired boilers may be set by federal, state, or regional agencies. As yet, the U.S. Environmental Protection Agency has not promulgated New Source Performance Standards for wood-fired boilers. The current particulate emission standard for a wood-fired boiler in Mississippi is 0.3 gr/dscf (68.6 gm/m^3) at 40% opacity (Reference 28).

Control equipment for particulate removal are either of the wet (scrubbers) or dry (cyclones, baghouses, electrostatic precipitators) type. The system selected should have sufficient control equipment to reduce the particulate emissions to approximately 0.1 gr/dscf (22.9 gm/m^3). Particulates removed from the stack will not be re-injected into the boiler but will be landfilled along with the boiler ash.

In addition, there will be dust emissions resulting from the harvesting, chipping, transporting, handling, and storing of the wood chips. Actual emission from these sources will vary widely, depending on the chip size, moisture content, and soil and weather conditions. If the chips are both damp and relatively large (greater than 0.5 inch [0.013 m]), no serious particulate emissions are expected from the handling of the chips. The frequency and condition of the roads on the NSTL site are generally quite good and should help minimize air-born particulates from the movement of heavy equipment.

Nitrogen Oxides and Sulfur Dioxide Emissions

Although wood-fired boilers also produce gaseous pollutants such as carbon monoxide, oxides of nitrogen and sulfur, and unburned hydrocarbons, little accurate information is currently available about either the quality or quantity of these emissions. Proper design of the combustion chamber and proper operation of the boiler minimize these emissions, but they are still present.

Wood, unlike coal or oil, has a negligible quantity of sulfur, and sulfur dioxide emissions are therefore very low. The estimated SO_2 emission rate of 0.07 lb/10^6 Btu (0.3 kg/TJ) for a wood-fired boiler (Reference 31) is significantly lower than the 1.2 lb/10^6 Btu (516 kg/TJ) Federal New Source Performance Standards for coal-fired power plants. No SO_2 removal system will be required.

Nitric oxide (NO) and nitrogen dioxide (NO_2), commonly referred to as NO_x, are important in the formation of smog. The estimated NO_x emission rate of 0.17 lb/10^6 Btu (70 kg/TJ) is significantly lower than the 0.7 lb/10^6 Btu (301 kg/TJ) Federal New Source Performance Standards for coal-fired power plants of comparable size dispite the large quantities of excess air normally used in burning wood. In a low population density area such as southern Mississippi, NO_x controls will not be required. Should such requirements be set by the State or become necessary to meet Federal ambient air quality requirements, the present state-of-the-art calls for modification of the combustion process, rather than use of

collectors or scrubbers employed for other types of atmospheric pollutants. For example, modification of the boiler design to restrict excess air could be employed to reduce NO_x emissions. In addition, some hydrocarbon, CO, and NO_x will be emitted by the heavy equipment used to harvest, chip, transport, and unload the wood chips.

Review of the available data indicate that very little direct information on the carcinogenic nature of emission from wood waste combustion exists. There appears to be some evidence that carcinogenic compounds may be emitted, but in a very low concentrations, from the combustion of wood, with the amount being proportional to the degree of incomplete combustion. These compounds include genzo (a) pyrene/benzo (c) pyrene, dibenzo (a,h) anthracene, dibenzo (def, mno) chrysene, benzo (g, h, i) perylene and indeno (1, 2, 3 -cd) perylene. There is no evidence that such emissions will be significant enough to threaten the local air quality or local health. Emissions of these materials, for example, are estimated to be less with wood-fired than for a correspondingly sized coal-fired power plant (Reference 31).

No disposal problems have been identified for the disposal of boiler ash and fly ash. The boiler residue is composed primarily of inert alumina and silica with trace amounts of heavy metals. The normal procedure would be to transport the collected ash to either a sanitary landfill or a dump for disposal. Since the operation of the NSTL wood fired boiler plant will include a forest management operation, the recovered boiler and fly ash can be returned to the forest and used as fertilizer.

Information on-by-product uses for wood ash is at this time limited. While several sources briefly mention the possibility of employing boiler ash as a soil conditioner, no detailed information has been presented regarding the success or failure of any such attempts. If the ash is uncontaminated, its soil conditioning value may be twofold: 1) The ash helps "break up" the heavy clay soil, adding permeability, and making the soil more manageable, and 2) the alkaline ash helps raise the pH in the acidic soils to a more acceptable growth promoting level (Reference 32). The ash may have some value as a forest fertilizer in those areas where clearcutting has occurred, inasmuch as commercial fertilizers are already considered to be in short supply. The ash contains all of the essential elements for shrub and tree growth except carbon, hydrogen, oxygen, and nitrogen that were driven off as gases in the burning process (Reference 15). There is an abundant supply of carbon, hydrogen and oxygen in air and water so their loss is not a matter of concern. It has been reported that when wood ash is used as a fertilizer, the general soil enviornment is more conducive to survival and growth of micro fauna and flora capable of capturing atmospheric nitrogen (Reference 32). However, nitrogen and phosphorus will still have to be made up from other fertilizer sources.

Although all the boiler manufacturers TRW contacted used landfill as their method for disposing of the ash, TRW recommends the use of ash as a soil conditioner as a part of the NSTL forest management plan.

Legal Concerns of an NSTL/MSAAP Biomass-to-Energy Plant

A major question concerning the development of a facility and the feasibility of a biomass energy source is that of state licensing or permit procedures, and regulatory and control processes. These considerations are themselves an issue of concern with respect to their effects on total costs and timing of development at the NSTL/MSAAP complex.

Generally, all of the states and many local governments have licensing procedures governing energy facilities siting, land use, zoning and environmental protection. Since the NSTL/MSAAP complex is located on federally-owned land, any state licensing issue will relate to environmental protection, i.e., air emission and water quality permits, solid waste disposal license and environmental studies. Rules for designing, constructing and/or operating energy facilities, which are possible sources of emissions to the atmosphere, are the responsibility of the states by virtue of the Clean Air Act of 1970 and the amendment of 1977. Day-to-day enforcement of the Clean Air provisions is sometimes delegated by the states to individual cities or air basins. As a result, the states implement permit or licensing procedures which establish restrictions on the sources of a pollution within their boundries so that federally set "ambient standards" can be met. Licensing aspects regulating the discharge of process water into lakes, rivers or streams which affect these receiving waters in terms of their overall dissolved oxygen, temperature, turbidity and odor, will also impact this operation.

The success of a biomass-to-energy operation at NSTL/MSAAP depends on the procurement of reliable sources of supply of energy wood. Contractual arrangements were investigated to assure uninterruped deliveries from suppliers. The availability of wood trash from lumber yards or suppliers would require a contractual arrangement calling for delivery from the supplier to the site at a price which is subject to negotiation. This information will consequently determine the type of contractual arrangements required, e.g., a requirements or an output contract.

Assuming that persons other than contractor and government personnel will be working near the operating site, it may be necessary to consider the procurement of insurance coverage to protect against bodily injury or property damage to third persons coming onto the premises at the request of the contractor. In this connection, the contractor would also include in its contract with NSTL/MSAAP a provision calling for indemnification from all losses incurred, whether directly or indirectly, arising out of the acts of government personnel.

TRW has identified International Paper Company as a possible supplier of wood trash, subject, however, to an exchange agreement calling for the transfer of sawtimber. Legal review discloses that NASA is permitted by statute to enter into and perform those functions incidental to its conduct of work. Pursuant to Title 42 United States Code Annotated, 2743(c) (5) and (6), NASA is vested with certain powers which include the right "to enter into and perform such contracts, leases, cooperative agreements, or other transactions as may be necessary in the conduct of its work and on such terms as it may deem appropriate, with... any person, firm,

association, (or) corporation..." This broad statutory grant enables NASA to perform a variety of activities to accomplish its stated objectives. The exchange proposal providing energy wood in return for government sawtimber can be accomplished through customary contractual arrangements. Private entities may therefore be granted access onto federal lands to harvest government timber consistent with the negotiated terms of the exchange and subject to any security access regulation(s). The exchange proposal appears to be the only vehicle through which NSTL/MSAAP will be able to utilize the higher value sawtimber to procure increased quantities of the lower value energy wood. Sale of the sawtimber to facilitate procurement of energy wood appears unfeasible. Revenue derived from the sale of government property goes directly to the Treasury Department and NSTL/MSAAP would therefore lose the benefit of the bargain. There appears to be no procedure through which NSTL's appropriation could be credited for such sales and thereby obtain the use of these moneys.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Direct combustion and pyrolysis were the two wood energy conversion technologies initially considered applicable to the requirements of NSTL/MSAAP. The most critical criterion for the wood to energy technology was that a process or system based on the technology be available for evaluation during the study period. Only direct combustion systems could meet this criterion. Pyrolysis technologies were conceptually attractive because they produce gaseous and oil products which have the potential for being useable in the existing CHP and TAHP HTHW generators with some alteration in the fuel feed and firing systems. However, pyrolysis, especially to produce oil and gas, has been demonstrated only at the pilot plant scale to date. The required alterations to existing furnaces to fire pyrolysis oil or gas are still being studied. Of the methods of applying direct combustion technology, spreader stoker type furnaces were selected. Manufacturers of spreader stoker wood-fired furnace boilers have, perhaps, more experience in the design and operation of wood fired system systems than those of competing types of systems such as suspension furnaces or fluid-bed furnaces. Stoker manufacturers would not retrofit the existing NSTL fossil fuel HTHW generators to fire wood. Since any type of retrofit would result in a substantially derated system, it was decided that the existing HTHW generators should not be converted to fire wood but should remain operable as spare, offline furnaces. In this way, the new wood-fired system would not require the extensive quantities of spare equipment usually included in plant utility facilities and the overall economics of the wood fired system would be improved.

2. Three different energy wood plants were evaluated for NSTL/MSAAP; one which produced the NSTL HTHW requirements, one which produced the NSTL HTHW requirements and co-generated 2 MW of electric power, and a third designed to produce steam for the MSAAP. Since all three systems are essentially steam generating utility plants, the equipment used to treat boiler feedwater; treat makeup water and store condensate; generate hot water and power; and to transport hot water and steam to users is identically the equipment which would normally be utilized in a fossil fuel boiler utility plant. The equipment unique to energy wood is in the front end wood handling system, the wood fired boiler, the ash removal and the pollution control systems. Several bulk materials handling companies will supply entire wood handling systems from the truck dumper to the boiler feed bins and many will startup the systems to insure their proper performance. Wood fired stoker boilers are supplied by many of the most highly respected companies in the boiler industry, i.e., Babcock & Wilcox, Combustion Engineering, Foster Wheeler, Riley Stoker, etc. The boiler manufactures will work in conjunction with particulate control equipment suppliers and guarantee both the boiler performance and to meet particulate emissions regulations. Entire bottom ash handling and dewatering systems can also be supplied by several companies. Therefore all three NSTL/MSAAP energy wood systems are composed of equipment which represent available technology.

The NSTL Energy Wood Hot Water Generator consists of a wood fired boiler, energy wood handling system, ash removal system, boiler feedwater and makeup water treating system, a direct contact steam-hot water heater and a hot water transmission system to connect the TAHP users to the CHP users. The system will fire energy wood and generate HTHW sufficient to supply the total projected NSTL HTHW requirements from 1983. This energy wood plant has an estimated total capital requirement of $11 million 1983 dollars. The estimated savings in natural gas cost during the first year of operation is $2,390,000 at natural gas prices of $6.05/MCF ($.22/m^3). The simple payback is defined as the total capital requirement divided by the annual savings in natural gas. The payback period for the energy wood system is therefore 4.6 years. The ROI for the NSTL HTHW energy wood system based on the total plant investment of $9.9 million is 22.8%.

The NSTL/MSAAP Energy Wood Hot Water and Power Plant consists of a front end wood handling system, ash removal and hot water transmission system identical to the NSTL Energy Wood Hot Water Plant. However, the wood fired boiler is designed to generate superheated steam which is exhausted to a back pressure power turbine and electric power generator. The heat in the turbine exhaust steam is then used to generate the NSTL hot water in shell-and-tube heat exchangers. This energy wood plant has an estimated capital requirement of $14.4 million. The estimated savings in natural gas during the first year of operation is $2,390,000. The estimated savings in electric power costs are $397,000 with power at $.065/kw. Therefore the payback is calculated as the capital requirement divided by the sum of the natural gas and power savings. The payback of this energy wood system is 5.2 years. The ROI based on $12.9 million total plant investment is 20%.

The MSAAP Energy Wood Steam Plant is designed to the specifications for a MSAAP coal fired 130 psig (1 MPa) steam plant The plant consists of four equally sized boilers with a common energy wood handling system and boiler feedwater system similar to the NSTL and NSTL/MSAAP systems. The estimated capital requirement for this MSAAP plant is $23.1 million. The ROI compared to a 10,000 TPY (9 x 10^6 kg) coal fired steam plant having a total plant investment $29.1 million is 6.8%. Based on a total plant investment of $20.8 million, the ROI is 3.5%

3. Although sufficient wood in the form of NSTL fee and buffer area operable forest stands plus mill and harvesting residues are available within a 150 mile (240 km) radius of NSTL/MSAAP, the practical limit for the size of a biomass to energy unit is one that could eventually be supplied with wood from the NSTL forest alone. Given the application of a forest management plan based on a 25 year rotation cycle and designed to convert the current NSTL forest into an energy plantation, the maximum sustainable yield of biomass would be 1.5 x 10^{12} Btu/year (1595 x 10^{12} J/yr). In the years before the 15th year of the rotation cycle, the NSTL forest would be barely capable of supplying energy wood sufficient to meet the requirements of NSTL HTHW or NSTL HTHW and 2 MW alone. Since the requirements for a MSAAP peacetime steam plant are half those for NSTL, they can be met much sooner. A promising plan for alleviating the 8 to 15 year shortfall energy wood supply situation is to arrange for the

trade of sawlog and pole timber harvested from the NSTL mature forest stands for an equal value (higher volume) of energy wood in the form of mill and harvest residues.

4. The environmental advantages of installing and operating an energy wood plant are many. Biomass has the advantages over other fuels that it is virtually sulfur free with a low ash content relative to that of coal or residual oil and that its combustion will not interfere with the carbon dioxide balance of the earth. Wood biomass can be grown near where it is used. Its use does not have such environmental hazards as leaks and spills. It is a clean fuel in terms of pollutant emissions and it is relatively clean to handle and process. Total air emissions for a 100% wood-fueled system are comparable or less than that for alternative fuels.

5. The harvesting of wood from the NSTL forest and instituting a forestry management plan will result in the long term effect of an upgraded and faster growing forest. New growth that will result from thinning out the rough and disease species will result in a new abundant and convenient food source. This is a highly desired wildlife management objective. Forest fertilization offers a management tool to offset any long-term effect of nutrient removal due to harvesting practice. Soil erosion, associated with forest harvesting is due primarily to haul roads and skid trails. However, the well developed road network on the NASA site will minimize the need for new forest road construction. Proper forest management practices can mitigate any potential impacts on water quality and soil erosion. Removal of the stream canopy will result in increased water temperatures. However, buffer strips, left adjacent to streams are very effective in maintaining ambient water temperatures within a clearcut area. Properly planned cutting of timber stands tends to improve wildlife habitat. Good management can minimize visual impacts of timber cutting. With sound forest management practices, the use of the forest as fuel can, on balance, be of benefit to the overall forest ecosystem.

Recommendations

Given the advantages in the economics and to the environment of operating a biomass to energy system at NSTL/MSAAP, it is recommended that a follow up design study to this study be conducted.

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APPENDIX A. NSTL CENTRAL AND TEST AREA HEATING PLANTS

The HTHW System used in the CHP is a flooded, forced-circulation hot water system which is composed of three hot water generators, four recirculation pumps, three supply pumps, a sediment tank, inert-gas expansion tanks, and necessary valves, instrumentation, and piping. Water in the closed system is heated in the HTHW generators to approximately 340°F (171°C) at a pressure of approximately 260 psig (1.8 MPa). The high temperature hot water is pumped through insulated underground pipes to buildings in the administrative, maintenance and storage areas of the NSTL. The high temperature hot water is used at these stations for operation of the heating and air conditioning systems and for domestic hot water. The high temperature hot water, cooled under full load conditions to approximately 250°F (121°C) by the user station heat exchangers, is returned through the insulated underground pipes to the CHP. The return high temperature water flows through a sedimentation tank to remove impurities. The return water is then pumped through the HTHW generators to be reheated and recycled through the system.

An expansion system, consisting of two expansion tanks pressurized with nitrogen, is included to compensate for changes in temperature and pressure due to variations in the demand for high temperature hot water. The expansion system includes safety relief valves which open when the system pressure reaches 425 psia (2.9 MPa). A makeup-system, a tank and two pumps, are also connected to the system return lines to permit replacement of the small water losses that occur in the distribution system.

Packings and bearings of the recirculating and supply pumps are cooled by water provided by a seal pump system. This system consists of two pumps, a distribution system, and a cooling tower. Water flows into the recirculating and supply pumps, cools the pump seals, then flows to the cooling tower. The water is cooled and circulated to the seal pumps where it is recycled. The full load operating characteristics are presented in Table A-1. One or two of the HTHW generators are in use at any time, permitting servicing of the third generator. A generator not in operation is kept in standby condition by circulating high temperature hot water through it without firing the burners. The generators can be fired using natural gas or No. 2 diesel oil as fuel. In normal operation, natural gas is used and the fuel oil supply maintained for emergency or back-up operation. Either natural gas or butane gas is used to provide pilot fuel. Each HTHW generator is equipped with a soot blower system to keep the generator clean and efficient.

The HTHW system used in the TAHP is composed of three packaged generators of the controlled forced circulation type. Each is rated for a continuous capacity of 15 x 10^6 Btu/hr (4.4 MW). There is a dual system such that either natural gas or RP-1 fuel may be fired. The hot water pressure is maintained at 425 psig (2.9 MPa) by a nitrogen cover in high pressure expansion tanks. The system is designed to supply 400°F (204°C) hot water with 250°F (121°C) return water. The furnaces and tubes were manufactured by the International Boiler Works Company of East Stroudsburg, Pennsylvania. The full rate operating characteristics of these furnaces are also presented in Table A-1.

Table A-1. Full Rate Design Characteristics

	Central Heating Plant Each of Three HTHW Generators	Test Area Heating Plant Each of Three HTHW Generators
Design Load		
Btu/H	40,000,000	15,000,000
watt	11,727,000	4,396,000
Boiler Efficiency		
Oil Firing, %	81	81.9
Gas Firing, %	79	79.55
Water Flow Through Generator		
lb/H	256,000	96,000
Kg/s	32	12
Design Pressure		
psig	550	450
10^6 Pa	4	3
Outlet Water Temp.		
°F	400	400
°C	204	204
Return Water Temp.		
°F	250	250
°C	121	121

APPENDIX B. MSAAP

The MSAAP is divided into three areas: Projectile Metal Parts, Cargo Metal Parts, Load Assemble and Pack and the necessary support facilities. The furnaces of the Projectile Metal Parts area will be used to provide the heat required to form 155 mm shells, From the hot steel forging of 88 pound (40 kg) billets, the metal is cooled from 1600°F (871°C) to ambient in multizoned oil-fired slow cool furnaces. The cooled forgings are then blasted with metal shot to remove the surface scale from the internal surfaces. Forgings are cleaned, pickled, phosphate- and soap-coated in preparation for the cold-draw operation. An alkaline bath and rinse is used to remove residual draw lubricant prior to stress relief. The oil-fired stress relief furnaces operate at 900°F (482°C) followed by 600°F (316°C) air and then water-cooled zones. The shell bodies are then subjected to a heat treatment which consist of austenitizing, quenching, and tempering operations designed to produce mechanical properties of 140,000 psi (965 MPa) minimum yield strength and 12% minimum elogation. Vapor degreasing, spray cleaning, and drying operations are performed so that the band material can be welded onto the body. Another surface treatment operation is performed to establish a suitable base for painting. The body is then wrapped with fiberglass and conveyed to oil-fired curing ovens. The base of the shells are forged from 4.5 pound (2 kg) slugs. They are subjected to an alkaline etch to remove scale before being heat- and solution-treated and artificially aged in oil-fired high heat, quench heating, and ageing furnaces. They are then anodized in preparation for assembly. The ogive of the shell is made from a 5.5 pound (2.5 kg) slug which is hydraulically forged/pressed prior to alkaline etch. The ogives are then heat- and solution-treated in oil-fired furnaces similar to those used for the base.

There will be 16 oil fired furnaces and eight special atmosphere generators in the Cargo Metal Parts area. The first operation in this area is to convey metal parts through four degreasing tanks to provide the clean surfaces required for the subsequent operations. Blank discs which will be used to form the cap end of the grenade are subcritically annealed in four oil fired furnaces at 1225°F (663°C) in a controlled atmosphere to remove the cold working stresses from the embossing and blanking operations. The necessary furnace atmosphere is produced by the controlled combustion of fuel oil in atmosphere generators exhausting into the furnaces. Four more annealing furnaces are used to perform a similar type of annealing on other work pieces to prepare them for further manufacturing operations by removing the cold work stresses induced by the draw operation. The annealed discs are automatically conveyed to the draw and resize operation where they are progressively drawn into the shape of the cap end of the grenade. The subsequent step is to restrike the disc to produce the final configuration of the cap end. Bodies are transferred from grinding to the internal machine station where the recessed groove is machined. The bodies are heat-treated in four fuel oil-fired austempering furnaces and four quenching furnaces to develop the required mechanical properties. A controlled atmosphere is utilized in these furnaces generated by the partial combustion of propane in atmosphere generators. Phosphatizing surface treatment is the final operation in the Cargo Metal parts area which establishes a suitable surface for painting.

There will be three explosive waste incinerators which will be fired with fuel oil and a propane fueled contaminated waste incinerator in the Load Assemble and Pack area. The explosive waste incinerators will be rotary kiln incinerators used to dispose of the propellent and explosive particles released on the manufacturing line and collected from the sumps and non-specification finished munition products. It is projected that only one furnace will be used most of the time, perhaps five hours per day, one day a week, and the other two will be on standby. The fuel oil consumption listed is for peacetime operation in which half the available furnaces will be in operation. The mobilization fuel consumption is therefore six times the quantities listed in Table B-1 since mobilization involves three times the working time and would utilize all the furnaces.

Table B-1. Projected 1983 Fuel Oil Consumption for MSAAP

MSAAP Area	Furnace	Fuel Oil Consumption* 10^6 Btu/H	MW	Approximate Temperature Required °F	°C
Projectile Metal Parts:					
	Slow cool furnace	3.98	1.17	1400 to 1600	760 to 870
	Stress relief furnace	3.98	1.17	900, 600	480, 320
	Austenitizing furnace	7.08	2.08	1200	650
	Tempering furnace	3.45	1.01	1100	600
	Fiberglass cure furnace	1.25	0.37	350	180
	High heat furnace	1.37	0.40	900	480
	Quench heating furnace	3.98	1.17	700	370
	Aging furnace	0.66	0.19	600	320
	High Heat furnace	1.37	0.40	900	480
	Quench heat furnace	3.98	1.17	700	370
Cargo Metal Parts:					
	Aging furnace	0.66	0.19	600	320
	Annealing furnace (2)	5.31	1.56	1225	650
	Annealing furnace (2)	5.31	1.56	1100 to 1400	600 to 760
	Austempering furnace (2)	7.96	2.33	1200	650
	Quench Heater (2)	.276	0.08	900	480
Load, Assemble and Pack:					
	Explosives incinerator	1.288 (260 H/yr,5 H/day)	0.38	1600 to 1700	870 to 930
Support:					
	Electric generator	61.4 (2860 H/yr)	18.0		

Of the fuel oil energy consumed for the projectile furnaces, 56% is transferred to the product. The electric generator operates at an efficiency of 36.4% to produce 6550 kw.

* Peacetime rate, 2080 H/year

APPENDIX C. SURVEY OF NSTL FOREST RESOURCES

The fee area of the National Space Technology Laboratories lies entirely within the Coastal Flatwood of the Gulf Coastal Plain. Soils developed from the marine sediments are generally poorly drained except on slope breaks to the major drainage ways of the area; soils on the breaks range from somewhat poorly to moderately well drained. The northern portion of the buffer zone is in the extreme southern portion of the Lower Coastal Plain, an area of drier soils and gently rolling terrain. Although the lands are highly productive for wood fiber, the NSTL fee lands are grossly understocked. Only approximately 10% of the lands in both the fee area and the buffer zone can be considered as "normally" stocked, and it is estimated that, taken as a whole, the lands are generally carrying less than 50% of their capacity.

Both aerial inventory and ground survey methods were used to estimate the NSTL forest inventory. Infrared imagery and a 4X enlargement of the entire fee area and a large portion of the buffer area was obtained from the EROS Users Assistance Center. The 1974 color infrared image was supplemented by a 1/40,000 black and white imagery obtained in 1976.

The ground survey was accomplished using maps of the NSTL area supplied by NASA. Cruise lines which would intersect dominant stand condition classes were marked on the maps to prepare a preliminary stratification. A two man crew then surveyed the selected areas utilizing standard surveying techniques. At each point merchantable trees were recorded by species, diameter breast high (DBH), and both total and merchantable height to a four inch (0.01 m) top diameter. Non-merchantable trees and understory vegetation from 1.0 to 5.4 inch (0.02 to 0.14 m) DBH were recorded for each of four, one-milacre (4.05 m^2) plots located on point diagonals, 1/4 chain from point center. Non-merchantable trees were recorded by species group (soft hardwood, hard hardwood, pine), DBH, and total height.

Based on the ground observation of current land cover condition, an extrapolation was made to the 1974 imagery. The stand conditions were identified by variation in species composition of the overstory, stand height, and stand density as indicated by individual tree crown size and density. Individual tree volumes were determined, the plot volume summarized, and converted to per acre values by the appropriate factor as illustrated in Table C-1. Individual point samples were summarized by condition classes, and the average per acre volumes were multiplied by the area of that particular stand condition class.

The conversion of cords to tons was made assuming that one cord of slash pine is approximately 90 cubic feet (2.55 m^3) of solid wood. The weight of a cord of slash pine in coastal Mississippi is 5400 pounds (2.45×10^3 kg) at a moisture content of 90% on a dry weigh basis. Therefore the dry weight per cord is 1.42 tons (1.29×10^3 kg), that is 5400 divided by 1.9 and converted to tons. Hardwood timber was assumed to weigh 1.5 dry ton (1.4×10^3 kg) per cord. Understory tonnages were based on reported dry weight per stem of a given DBH class assuming a 3:1:1 soft hardwood, hard hardwood, pine mix with an average specific gravity of 0.44. Topwood and stump/root volumes were determined as a percentage of merchantable volume according to researchers such as Switzer, Nelson, Koch and Byrd. Figures used are given in Table C-2.

Table C-1. Representative Volume Computations

Stand Class	Cords/Acre $\bar{x}$	Cords/Acre s	Cords/Acre CV	Mbf/Acre $\bar{x}$	Mbf/Acre s	Mbf/Acre CV	Understory Tons/Acre $\bar{x}$	Understory Tons/Acre s	Understory Tons/Acre CV	No. Plots
6	1.3	.9	70%	.53	1.06	200%	36	41	114%	4
9	2.6	2.4	92%	.26	.64	246%	17	18	106%	6

Mbf = 1000 board feet
Cords = 128 cu. ft. stacked wood
$\bar{x}$ = average
s = standard deviation

CV = $\frac{s}{\bar{x}}$ x 100 = coefficient of variation; 60% for sawtimber, 103% for pulpwood

Table C-2. Topwood and Stump/Wood Based on Merchantable Stem Volumes

Species Group	Topwood cds	Topwood Mbf	Root/Stumps cds	Root/Stumps Mbf
	Percentage of Merchantable Volume			
Hardwood	23%	27%	20%	18%
Softwood	25%	16.5%	22%	15%

Examples of a field tally sheet with computations and the NSTL forest inventory data follow.

Fee Volumes/Acre

Type	Acres	Understory Dry T/A	Pine/Acre cds	Mbf	Topwood Cords	Roots/Stumps Cords	Hardwood cds	Mbf	Topwood Cords	Roots/ Stumps Cords
1	582	3	0	0	0	0	0	0	0	0
2	887	13	0.6	0	0.15	0.12	0	0	0	0
3	793	21	1.2	0	0.3	0.24	0	0	0	0
4	233	15	1.6	2.01	1.14	0.99	0	0	0	0
5	533	6	2.5	0	0.62	0.50	0	0	0	0
6	1048	31	1.3	0.53	0.52	0.44	-	-	-	-
7	526	8	1.5	0.80	0.67	0.57	-	-	-	-
7a	45	27	0.6	14.61	5.56	4.98	-	-	-	-
8	1235	12	2.4	0.97	0.96	0.80	-	-	-	-
8a	224	16	0.9	5.64	2.32	2.06	-	-	-	-
9	520	17	2.6	0.26	0.74	0.61	-	-	-	-
10	815	9	2.5	2.50	1.54	1.33	-	-	-	-
11	53	10	2.9	10.56	4.60	4.10	-	-	-	-
12	477	8	2.0	0.75	0.78	0.65	1.1	0.40	0.49	0.40
13	305	7	1.6	0.80	0.69	0.59				
14	199	23	3.5	1.40	1.39	1.34				
15	87	11	2.5	1.20	1.06	0.90				
16	244	18	-	-	-	-	8.3	0.35	2.12	1.97
17	80	10	6.3	0	1.58	1.26				
18	49	12	-	-	-	-	1.7	0	0.39	0.37
	8935									

Buffer Volume/Acre

Type	Acres	Understory Dry T/A	Pine/Acre cds	Pine/Acre Mbf	Topwood Cords	Roots/Stumps Cords	Hardwood cds	Hardwood Mbf	Topwood Cords	Roots/ Stumps Cords
1	220	3	0	0	0	0				
2	294	13	0.6	0	0.15	0.12				
3	257	21	1.2	0	0.30	0.24				
5	29	6	2.5	0	0.62	0.50				
6	47	31	1.3	0.53	0.52	0.44				
7	83	8	1.5	0.80	0.67	0.57				
8	11	12	2.4	0.97	0.96	0.80				
10	63	9	2.5	2.50	1.54	1.33				
11	55	10	2.9	10.56	4.60	4.10				
12	119	8	2.0	0.75	0.78	0.65	1.1	0.40	0.49	0.40
13	204	7	1.6	0.80	0.69	0.59				
15	114	11	2.5	1.20	1.06	0.90				
16	18	18	-	-			8.3	0.35	2.12	1.97
17	109	10	6.3	0	1.58	1.26				
19	688	13	1.8	0	0.45	0.36				
19+	92	6	3.7	0	0.92	0.74				
20	291	25	3.0	3.27	1.95	1.69				
22	164	18	5.5	1.87	2.06	1.72				
ACRES	2858									

Additional Forest Area Located in Buffer Zone

			Pine/Acre				Hardwood/Acre			
		Understory	Merch.		Tops	Roots/ Stumps	Merch.		Tops	Roots/ Stumps
Type	Acres	Dry T/ac	Cd	Mbf	cds	cds	cds	Mbf	cds	cds
1	31	3	-	-	-	-	-	-	-	-
3	81	21	1.2	-	.3	.24	-	-	-	-
8	89	12	2.4	0.97	.96	.80	-	-	-	-
11+	38	14	3.3	13.72	1.33	1.18	-	-	-	-
12	37	8	2.0	0.75	0.78	0.65	1.1	0.4	0.49	0.40
12+	44	12	4.3	1.25	1.53	1.36	4.7	0.7	1.50	1.22
16+	124	20	-	-	-	-	2.6	8.4	5.64	3.80
19+	29	6	3.7	0	0.92	0.74	-	-	-	-
23	59	13	0.7	9.56	3.68	3.34				
	532 acres									

Additional Forest Area Located in Buffer Area

	PINE				HARDWOOD				
	Merch.		Tops	Roots	Merch.		Tops	Roots	Understory
Type	cds	cds	cds	cds	cds	cds	cds	cds	tons
1	-	-	-	-	-	-	-	-	93
3	97	-	24	19	-	-	-	-	1701
8	214	192	85	71	-	-	-	-	1068
11+	125	116	50	45	-	-	-	-	532
12	74	62	29	24	41	33	18	15	296
12+	189	122	67	60	207	68	66	54	528
16+	-	-	-	-	322	2315	699	471	2480
19+	107	-	27	21	-	-	-	-	174
23	41	1253	217	197	-	-	-	-	2067
SUB-TOTAL	847	1745	499	437	570	2416	783	540	8939
TOTAL	2592 cds		936 cds		2986 cds		1323 cds		

Example of Field Tally Sheet With Computations

PLOT NO. E2 - Buffer TYPE Slash Sparse Sawtimber DATE 8/5/78

TOPO flat

SP. CODE

1. Loblolly Pine
2. Slash Pine
3. Shortleaf Pine
4. Longleaf Pine
5.
6.
11. Yellow Poplar
12. Sweetgum
13. Blackgum
14. Tupelogum
15. Cottonwood
16. Cypress
17.
18.
19.
20.
21. Red Oak
22. Cherrybark Oak
23. White Oak
24. Hickory
25. Ash
26. Elm
27. Cherry
28. Hackberry
29.
30.
31.
32.
33.

SP	DBH	MERCH. HT.	TOTAL HT.	MERCH. VOLUME
2	7.8	30	40	0.073 cd
2	18.0	72	88	550 bf
4	10.8	44	50	104 bf
2	5.5	12	24	n.m.
2	6.0	28	38	0.039 cds

NOTES

TOTAL MERCH. PLOT VOLUME

0.112 cds

654 Mbf

PER ACRE VOLUMES

1.12 cds

6.54 Mbf

PER ACRE UNDERSTORY TONNAGE

(SEE OVER)

23 tons

SUBMERCHANTABLE AND GROWTH ON BACK

APPENDIX D. DESCRIPTIONS AND DEVELOPMENT STATUS OF FIVE BIOMASS DIRECT COMBUSTION AND SIX PYROLYSIS PROCESSES

RESCO Refuse Burning Steam Generator (Reference 33)

Developer. Refuse Energy Systems Co., Saugus, Mass.

Process Description. The RESCO Refuse Burning Steam Generator is a biomass burning waterwall boiler with an operating capacity of 1200 TPD (13 kg/s). Municipal solid waste is received and stored in a pit sized to store refuse for more than five days operation. Overhead cranes serve as furnace feed hoppers. Two waterwall boilers (maximum capacity - 750 TPD [8 kg/s]) with three-section reciprocating grates operate at 1650°F (900°C) to produce 8.4 x 10^6 lb/day (44 kg/s) steam at 690 psig (4.85 MPa) and 875°F (478°C). The ash is quenched and landfilled.

Environmental Considerations. Two electrostatic precipitators are required to reduce particulate emissions below 0.05 grains/SCF (0.1 g/m^3) and the cleaned flue gas is discharged through a stack.

Economics. Capital costs for the 1200 TPD (13 kg/s) plant were slightly over $38 million. Minimum charges for the wastes were $13.00/ton ($14.00/10^3 kg). Revenues and operating costs are not available.

Status. The RESCO Steam Generator is based on proven technology developed by the Swiss Company, Von Roll. Feasibility studies were made in 1969 and construction began in 1973. Initial testing was performed in 1975. The facility is now fully operational.

Hamilton Solid Waste Reduction Unit (SWARU) (Reference 34)

Developer. Regional Municipality of Hamilton Wentworth, Ontario, Canada.

Process Description. SWARU is a semi-suspension fired steam generator. Incoming refuse is dumped into a pit with a conveyor, picked over manually to remove large materials, and carried to four vertical-shaft pulverizers. Ferrous metals are recovered magnetically and the remaining refuse is sent directly to the furnaces. The plant has two Babcock and Wilcox waterwall boilers, each with a maximum capacity of 300 TPD (3 kg/s). The prepared refuse is introduced by a swinging distribution spout and three parallel pneumatic injection chutes. The light combustibles burn in suspension while the heavier objects burn on a thin bed on the traveling grate. The ash is landfilled. SWARU is capable of generating 5.0 x 10^6 lb/day (26 kg/s) saturated steam at a pressure of 250 psig (1.82 MPa). Fifty to sixty percent of the steam is used in turbines for supplying plant energy requirements. The remainder is condensed in rooftop air-cooled condensers and recirculated.

Environmental Considerations. Two electrostatic precipitators in series are required for each boiler.

Economics. The initial cost of the SWARU system was $9 million, with plant improvements to correct operating problems estimated to cost an additional $1 million. In 1975, operating and maintenance costs totalled

over $2 million for disposal of 48,000 tons (43.5 x 10^6 kg) of solid waste, or a disposal cost of $44.10/ton ($48.60/10^3 kg).

Status. Design was initiated in 1968. The initial start-up was February, 1972. Commercial operation began in June, 1972.

Nashville Thermal Transfer Corp. (Reference 35)

Developer. Nashville Thermal Transfer Corp., Nashville, Tennessee.

Process Description. The Nashville system is a mass-burning, waterwall boiler with reciprocating grates. From the refuse pit, solid waste is charged by an overhead crane to the feed chute of the two furnaces and onto a four-section reciprocating grate stoker. Seven hundred and twenty TPD (7.6 kg/s) is the maximum capacity. The hot combustion gases generate steam in two boilers. Steam is produced at 400 psig (2.85 MPa) and 620°F (320°C).

Environmental Considerations. Electrostatic precipitators are required to remove the smaller particles (<5 μm) from the flue gas stream.

Economics. Initial costs were $16.5 million, but problems encountered in start-up resulted in an additional $8 million. Operational costs and revenues are not presently available.

Status. Design was started in early 1971 and construction in June, 1972. Incineration of municipal solid waste began in 1974. A number of operating problems were encountered: 1) water tube failure, 2) control system failure, 3) noncompliance with air quality standards due to reliance on a wet scrubbing system for flue gas cleanup. Electrostatic precipitators have replaced the wet scrubbers, and the other problems have been corrected.

CPU - 400 (Reference 36)

Developer. Combustion Power Company, Menlo Park, California.

Process Description. CPU-400 is a refuse-fired high pressure fluid bed incinerator coupled to an open cycle turbo-electric generator system. Pilot plant testing has been on a 100 TPD (1.05 kg/s) unit. A feed preparation system consisting of two shredders, an air classifier, and a ferrous metals recovery system is utilized. The light fraction from the air classifier is taken to a refractory-lined fluid bed combustor, 7.1 feet (2.2 m) in diameter and 14 feet (4.3 m) high. Two rotary airlock feeders introduce the fuel to the bottom of the combustor at 100 lb/min (0.76 kg/s). Air at 58 psia (0.4 MPa) is used to fluidized the sand and provide combustion air. The combustion gases flow through a gas cleanup system to remove particulates before being sent to the turbine. A 1000 kw axial flow gas turbine is used to recovery energy from the hot gas stream.

Environmental Considerations. Because the CPU-400 is still being tested, little work has been done to establish the effluent stream characteristics of this system.

Economics. An economic analysis for a 600 TPD (6.3 kg/s) facility was published in 1974. The installed capital cost was set at $10.8 million, with an annual operating cost of $2.5 million. Annual revenues from the sale of electricity were estimated to be $1.1 million. The estimated disposal cost was $6.90/ton ($7.60 x 10^3 kg).

Status. From 1968 to 1970, subscale experiments were performed to evaluate basic equipment. The pilot plant was designed and built between 1970 and 1973. In 1974 tests were completed using wood wastes for Wayerhaeuser Co. The facility is still being tested.

The most severe problem in the pilot unit has been cleanup of the feed gas to the turbines. Severe particulate loading has caused solids to be deposited on the turbine blades. The status of this cleanup technology is judged to be in the developmental stages.

Longview, Washington, Plant Power Boiler (Reference 37)

Developer. The Weyerhauser Company, Longview, Washington.

Process Description. The Longview Plant Power Boiler is a wood waste semi-suspension fired steam generator. Wood wastes and bark chips are dried to a moisture content of 30 to 35 percent. A large part of the fuel is burned in suspension. The final burnout takes place on a grate. The steam produced in the boiler tubes is expanded through turboelectric generators to produce 5.5 x 10^4 lb/hr (6.9 kg/s) of steam at 1250 psi (8.71 MPa) and 950°F (510°C).

Environmental Considerations. Because the Longview Power Plant Boiler is still in the test stages, little work has been done to characterize the effluent streams. However, it has been established that electrostatic precipitators cannot be used on wood-fired furnaces because of the resistivity of the fly ash. Bag houses will probably be suitable.

Economics. No data have been released on the capital or operating costs.

Status. The technology has been in the testing stages since early 1976.

Purox System (Reference 38)

Developer. Union Carbide Corporation

Process Description. The Purox system is a combined partial oxidation-pyrolysis system producing a nitrogen-free synthesis gas with a HHV of 370 Btu/scf (14.7 MJ/Nm^3). The process utilizes oxygen for combustion and

operates at slightly above atmospheric pressure. The 200 TPD (2.1 kg/s) demonstration plant has been used to convert municipal refuse to syngas. The gasifier is a vertical shaft reactor approximately 10 feet (4.5 m) in diameter and 30 feet (14 m) high. The refuse is injected near the top of the reactor, slowly descends as a moist feed, and is converted to gases, liquids, and char as it is contacted by hot gases. The char ash which is formed descends into a hearth at the bottom of the gasifier where the char is completely burned with oxygen forming the nitrogen-free hot gases which pyrolyze the refuse. The moisture in the refuse (approximately 25%) plus the water formed by the pyrolysis reactions constitutes 40 percent of the reactor off-gases. After drying, the syngas contains 24% H_2, 40% CO, 24% CO_2, 5.6% CH_4, 1% H_2, and 5.4% higher hydrocarbons. The production rate is 18,800 scf of dry gas per ton of MSW (.555 Nm^3/kg MSW). The heating value of the gas is 370 Btu/scf (14.7 MJ/Nm^3). The syngas can be used as a fuel or converted to other products such as methanol or ammonia. It can also be utilized directly in a gas-turbine, combined-cycle, electric power plant or can be compressed and piped to a utility power plant.

Other major components of the Purox process in addition to the gasifier are: 1) a feed preparation system which separates metals and shreds the municipal solid waste (may not be necessary when using the Purox system on biomass), 2) an oxygen plant to supply the oxidizing medium, and, 3) a gas cleanup system (which may or may not be necessary depending on the use of the syngas).

Environmental Considerations. It is not expected that utilization of the Purox system for biomass will present special pollution problems. Potential air pollutants are removed in a baghouse. Ash can be disposed of as landfill. The spent scrubber water can be recycled after treatment with available water pollution control technology.

Economics. For a proposed 1500 TPD (16 kg/s) system, annual operating and capital costs are estimated at approximately $7 million (1976 estimate). The estimated cost of waste disposal is $15.56/ton ($17.16/10^3 kg). This does not include by-product credit from the sale of syngas or electricity, waste disposal revenues, or revenues from the sale of reclaimed metals.

Status. A 5 TPD (0.05 kg/s) pilot plant was built in Tarrytown, N.Y. in 1970 and operated for three years. A 200 TPD (2.1 kg/s) demonstration plant was built in South Charleston, West Virginia in 1974 and is still operating. Full-scale commercial units are available.

Occidental Flash Pyrolysis (Reference 34)

Developer. Occidental Research Corp., LaVerne, California.

Process Description. The Occidental Flash Pyrolysis System produces a liquid, which when blended with No. 6 fuel oil, can be used in existing burners. The feed preparation system is crucial to the Occidental Flash Pyrolysis system. It consists of a primary shredder, a magnetic separator, and an air classifier. The heavy fraction from the air classifier is further treated to separate glass and nonferrous metals. The light

fraction from the air classifier is dried in a rotary kiln where the moisture level is reduced to approximately three percent. The dried material is then screened. Material passing through a 14 mesh screen is sent to an air table where three fractions are recovered. The heavy, glass-rich fraction is sent to a glass recovery plant. The intermediate fraction is landfilled. The light fraction is combined with the material which does not pass through the screen. This combined stream is transported to a secondary shredder and then to the "flash pyrolysis" reactor. The Occidental fuel production occurs in a rapidly moving gas stream. The finely ground organics are entrained with hot char in a recycled synthesis gas stream. The off-gases consist of a synthesis fuel gas, a condensible vapor, char, and ash. A cyclone is utilized to remove the char and ash. The vapors are then cooled with a light fuel oil spray to condense a fuel oil product. The remaining gaseous fuel is burned with about half of the char to generate the heat required for pyrolysis. The reactor effluent gases contain 20% char, 40% oil, 30% gas, and 10% water. One barrel of oil is generated per ton of refuse (170 m^3/kg) having a HHV of 10,600 Btu/lb (24.6 MJ/kg) and a specific gravity of 1.3. The net thermal efficiency is 36 percent for oil production.

Environmental Considerations. Environmental controls necessary for the present test/demonstration facility have not been completely determined. As with most pyrolysis systems, however, it is expected that the environmental impact will be minimal with proper, state-of-the-art pollution control equipment.

Economics. In 1976, the total capital cost for a 200 TPD (2.1 kg/s) pilot plant was estimated to be $28.6 million. Operating costs were estimated to be $17.30/ton ($19.07/10^3 kg), resulting in a total cost of $26.49/ton ($29.21/10^3 kg). Revenues are expected to be $12.37/ton ($13.64/10^3 kg). The net cost of waste disposal is $14.12/ton ($15.57/10^3 kg).

Status. Occidental (previously Garrett Research) began work in 1968 to develop a 7 TPD (0.07 kg/s) pilot plant. Construction of a 200 TPD (2.1 kg/s) pilot plant was begun at El Cajon, California in 1975. Testing of this plant began in 1977.

Andco-Torrax Pyrolysis System (Reference 34)

Developer. Andco, Inc., Buffalo, N.Y.

Process Description. The Andco-Torrex system utilizes pyrolysis to convert municipal refuse into fuel gas. The gas is burned to produce heat for the generation of steam. Untreated refuse is introduced near the top of the reactor. The refuse descending through the reactor is first dried by the surrounding hot gases and then converted to gases, char, and ash. The char is burned at the bottom of the reactor with air preheated to a sufficient temperature to cause slagging of the ash and metals (2000°F [1090°C]). The temperature of the gas leaving the top of the reactor is approximately 800°F (430°C). To take advantage of the

sensible heat content of the gas, a secondary combustion chamber must be closely coupled to the gasifier. High temperatures maintained in the secondary combustion chamber cause the flyash and other inert carryover materials to melt, fuse, and form a slag which separates from the gas stream. Most of the combustion products from the secondary combustion chamber are directed to a waste heat boiler. The remaining portion is directed to preheat the air for gasification. The net thermal efficiency of this system is approximately 58 percent.

Environmental Considerations. For most municipalities, an electrostatic precipitator is the only stack gas cleanup unit required. Ash is landfilled.

Economics. For a 1000 TPD (10.5 kg/s) plant, capital costs are estimated to be $34.6 million. Annual operating costs are estimated to be $2.7 million.

Status. Torrax Systems, Inc. was created in 1976 by Andco, Inc. and the Carborundum Company. Since 1972, a 75 TPD (0.79 kg/s) demonstration plant has operated as a development facility. Wastes such as sewage, oil, PVC, and tires have been pyrolyzed along with MSW. A 200 TPD (2.1 kg/s) plant in Luxembourg started up in late 1976. Large scale plants are under construction in France and Germany.

The Monsanto/Landgard System (Reference 38)

Developer. Monsanto Corporation, St. Louis, MO.

Process Description. The Monsanto/Landgard system is a partial oxidation/pyrolysis system utilizing an auxiliary fuel to generate the heat for pyrolysis. The system is operated on a semi-batch basis. The refuse is shredded and the ferrous metals are removed in the feed pretreatment plant. The remaining combustibles and inorganics are fed to a sealed rotary kiln where an auxiliary fuel oil burner produces the heat necessary for pyrolysis. The nitrogen-rich synthesis gas is burned completely with secondary air in a separate combustion chamber. The hot combustion gases are passed through a waste heat boiler to generate steam. Gas clean-up systems are determined by the standards of the municipality in which the Monsanto/Landgard system is located.

Environmental Considerations. A well publicized problem with the 1000 TPD (10.5 kg/s) Landgard Demonstration unit in Baltimore, Md. has been the failure of the system to meet air pollution standards. A wet scrubber has been used to clean the gas, but studies are currently under way to determine how the gas cleanup system can be upgraded.

Economics. The capital costs were in excess of $20 million, and operating costs are estimated to be $7.60/ton ($8.38/10^3 kg). Amoritizing the capital costs over a 20 year period results in a total disposal cost of $13.15/ton ($14.50/10^3 kg).

Status. A 35 TPD (0.37 kg/s) pilot plant was operated by Monsanto from 1969 to 1971. Construction of the 1000 TPD (10.5 kg/s) unit in the city of Baltimore took place from 1973-1975 with EPA support. Although the pilot plant met Maryland air pollution standards, the full-scale plant did not. Monsanto has withdrawn from the project.

Georgia Institute of Technology Mobile Agricultural Pyrolysis System (Reference 39)

Developer. Georgia Institute of Technology

Process Description. The processing scheme utilized by the Georgia Tech Engineering Experiment Station (EES) mobile waste-to-energy system is similar to the previously described systems (parial oxidation followed by pyrolysis). The 25 TPD (0.26 kg/s) pyrolyzer has inside dimensions of 5.3 feet (2.4 m) in depth and 2.6 feet (1.2 m) in diameter. Cellulosic feedstock (such as wood waste) passes down through a vertical shaft converter where it is first dried, then pyrolyzed by upward moving gases leaving the bottom combustion zone. The char from the pyrolysis reaction is oxidized in the combustion zone with air. Pyrolysis gases pass out the top of the converter and into a cyclone. A liquid fuel oil fraction is then condensed from the clean gas in an air cooled condenser. The remaining gases are burned to produce heat which can be used to dry incoming feed. Oil and unburned char are recovered from the process. The heating value of the solid material is approximately 14,000 Btu/lb (32.5 MJ/kg). The heating value of the liquid ranges from 12,000-14,000 Btu/lb (27.9 to 32.5 MJ/kg). Because gaseous fuel is of little utility in a mobile pyrolysis system, various process variables such as temperature, air/feed ratio, etc., must be adjusted to obtain optimal oil and char production.

Environmental Considerations. No information is available on effluent compositions or possible emissions resulting from the operation of the 200 TPD (2.1 kg/s) mobile pyrolysis unit. Proper operation is imperative in order to meet emissions standards. For example, if the pyrolysis gas is burned at too high a temperature, excessive amounts of NO_x will be formed. The potential exists for emissions from the drying system depending on the selection of the final dryer-mechanical separator equipment.

Economics. The economics of the Georgia Tech system are highly speculative, based on unknown operating parameters such as maintenance, production days per year, cost of the waste, and the selling price of the product. An analysis based on a proposed 100 TPD (1.05 kg/s) mobile system operating 250 days/year has been completed. Assuming a disposal charge of $3/ton ($3.30/10^3 kg) and a product sales price of $35/ton ($38.60/10^3 kg), a total annual operating cost of $250,000 was estimated and a net profit of $300,000 was calculated.

Status. The Georgia Tech Mobile Pyrolyzer is being tested and is not presently commercial. Experimental units ranging in size from six to 50 TPD (0.06 to 0.53 kg/s) have been operated.

Nichols-Herreshoff Furnace Process (Reference 40)

Developer. Nichols Engineering and Research Corporation

Process Description. The Nichols-Herroshoff Carbonizer is a multiple hearth furnace which permits continuous production of charcoal under conditions allowing maximum control. This furnace is available for charcoal production rates from one to four tons per hours (.25 to 1 kg/s).

The furnace consists of a series of circular hearths one above another in a refractory lined shelf. A vertical rotating shaft through the center of the furnace carries arms with rabble plows which move the material in a spiral fashion across each hearth. Raw material, green or pre-dried, continuously enters the top of the carbonizer and rabbles across it to pass through dropholes to the hearth below. In this way, the material moves over each hearth passing downward through the furnace until the product is discharged from one or more ports on the bottom hearth. As the material progresses through the furnace it is gradually dried, heated and carbonized. Evolved volatile matter provides the source of heat for the process. The combustible gases produced are in excess of the requirement for drying the wood. Depending on the site conditions, they are burned in a flare, used locally as a fuel gas, or burned for waste heat generation. The heating value is approximately 200 Btu per ft^3 (7.5×10^6 J/m^3), which is augmented by the sensible heat contained at temperatures of 800 to 1200°F (427 to 694°C). For a production of two ton/hr of charcoal (0.5 kg/sec) 50,000 pounds/hr (6.3 kg/sec) of high pressure steam can be produced per ton (907 kg) of charcoal produced. No oil product is practical. The volatile material content of the charcoal may be adjusted in the range of 10 to 20%, and this content is reported to be quite constant over a range of particle sizes from eight to 200 mesh.

Other equipment includes bulk handling systems and charcoal cooling and conditioning equipment to deliver finished charcoal in stable form to storage and briquetting operations.

Environmental Considerations. Environmental controls are primarily focused on the discharge gases which must be burned for smoke elimination.

Economics. A two ton per hour plant (1.8×10^3 kg) which offers exhaust gas heat recovery by producing 50,000 lbs/hr (6.3 kg/sec) of steam, is estimated at $1,700,000. Included in these estimates are the costs for auxiliary equipment such as wood hogging, storage and conveying, and product cooling and conveying. Any briquetting and packing facilities are not included in the foregoing. Equipment for the control of air emissions also are not included in this figure.

As the analysis below shows, the operation of a two ton per hour (1.8×10^3 kg) facility, which includes waste heat recovery as steam, can be economically attractive. This analysis assumes no cost for the waste wood feed - a situation which exists for large saw mills and pulp plants. If this waste must be trucked in, this cost can be added on the basis that 16 tons (14.4 metric tons) of wood waste, at 50% moisture, are required to produce two tons (1.8×10^3 kg) of charcoal. Note the

conditions assumed for this example. Since the cost and availability of feeds, labor, and fuels vary throughout the world, the figures shown can change considerably.

Operating Costs

1) Basis: Capital investment for a two ton per hour (1.8 metric ton) facility, including waste heat recovery as steam, operating 8,000 hours per year - $1,700,000.

2) Costs:

	Cost per Ton	Cost per 10^3 kg
a. Labor (2 men/shift, $6.00/ man-hr + 50%)	$ 9.00	$ 9.92
b. Utilities (500 hp @ $0.03/ kwh)	5.60	6.17
c. Maintenance (5%/yr on investment)	5.30	5.84
d. Depreciation (assume 10-yr straight line)	10.65	11.74
e. Supervision	1.40	1.54
f. Insurance and taxes (5%/yr on investment)	5.30	5.84
g. Miscellaneous	3.75	4.13
Total:	$41.00	$45.20

3) Generated steam value credit: Assuming fuel costs for generating steam of of $2.60 per 1000 pounds of steam (400 kg), at 50,000 pounds (22,680 kg per 1,800 kg) steam per two tons charcoal	65.00/ton	71.65
4) Added costs for briquetting facilities: Installation, operation, and maintenance, as above approx.	14.00	15.00
5) Added costs for air quality control: Facilities: Installation, operation, and maintenance, as above approx.	2.00	2.00

Status. Much, if not all of the current experience with charcoal production in the United States appears to have arisen from the use of the Nichols-Herreshoff process with a wood or wood waste feed. To date, Nichols has built over ten charcoal manufacturing plants using waste wood feed materials. In addition, they have done pyrolysis development work on sewage sludge and refuse and are presently building one of the first sludge pyrolysis units.

APPENDIX E. RESOURCE POTENTIALS FOR THE NSTL FEE AREA

The occurrence of various types of soils common to the Coastal Flatwoods is strongly related to relatively minor topographic expression. The Flatwoods is comprised of old marine terraces, Holocene or Recent, which have eroded into broad flat ridges and gently rolling topography. The natural drainage ways are poorly drained, loamy soils which are classified as Smithton, Guyton, and Atmore series. The ridges may only be five feet (1.5 m) higher in elevation than the ridge flats and depressional areas, but the drainage class of the soils becomes somewhat poorly to moderately well drained. Soil series in this group include Harleston, Poarch, Saucier, and a Saucier/Susquehanna complex. Slightly lower ridges are mapped as Escambia, a somewhat poorly drained soil. These soils occur only sporadically and in relatively small patches throughout the area, but with somewhat greater frequency in the east-central portion of the fee area, and from just east of old Route 43 to the Mike's River alluvial plain. A limited area along the western edge of the fee area is considered as alluvial and the soils are mapped as the Arkabutla-Rosebloom complex which is frequently flooded and suitable only for hardwood species.

Some concept of the magnitude of the terrain change within the uplands of the fee area might be gained from observing the average elevations. In the southern portion of the area, the ground elevation is about 20 feet (6.1 m) above sea level. As one progresses to the northeast, the elevation gently rises to a high of 35 feet (10.7 m), a change of 15 feet (4.6 m) vertically in approximately 20,000 feet (6100 m) horizontally, or an average slope of less than 1%.

The soil series, as indicated in Table E-1, have been grouped into landscape units or associations. A landscape unit represents a group of soils having similar properties; therefore, each group will have similar productive potential, similar restrictions for mechanized silvicultural operations, and similar suitability for a species of tree to be planted. There is one additional unit of soil materials - the "made-soils", or dredge spoil from the canal on the southern boundary of the area. The material is classified as a Sulfaquept, and the deposits range from sands to silty clays in texture and are strongly acidic with a high sulfur content. The large bulk of this material will require treatment if they are to be put into tree production.

The conventional method of expressing productive potential is site index which is the height that a dominant or codominant tree will have or was at a given base age, usually 50 years (Figure E-1). Growth and yield estimates, although highly influenced by variation in stocking density, are attached to the site index classes.

In general, the upland soils are well suited to the production of slash pine. Site index for the uplands ranges from 80 feet to 90+ feet (24 to 27 m) at age 50. Reported growth ranges from 1.75 to 2.00 cords per acre per year (432 to 490 cds/km^2/yr) for the soils with board foot growth ranging from 208 to 367 board feet per acre per year. These data are for natural, relatively fully stocked stands occupying sites which have not received any site preparation. Only Landscape Unit 4 is considered to be best suited for the production of hardwood species (Table E-1).

Table E-1. Soils of the Fee Area. Landscape Units, and Approximate Areas

Unit No.	Series	Landscape Unit	Approx. % of Forested Fee Area	Approx. Acres (km^2)
1	Harleston Poarch Saucier Saucier-Susquehanna	Moderately well drained ridges and upper slopes	8%	700 (2.8)
2	Escambia	Somewhat poorly drained low ridges	13%	1162 (4.7)
3	Smithton Guyton Atmore	Poorly drained; broad, flat ridges, depressional areas, drainages	71%	6344 (25.7)
4	Arkabutla-Rosebloom	Somewhat poorly and poorly alluvial plain; frequently flooded	8%	730 (3.0)

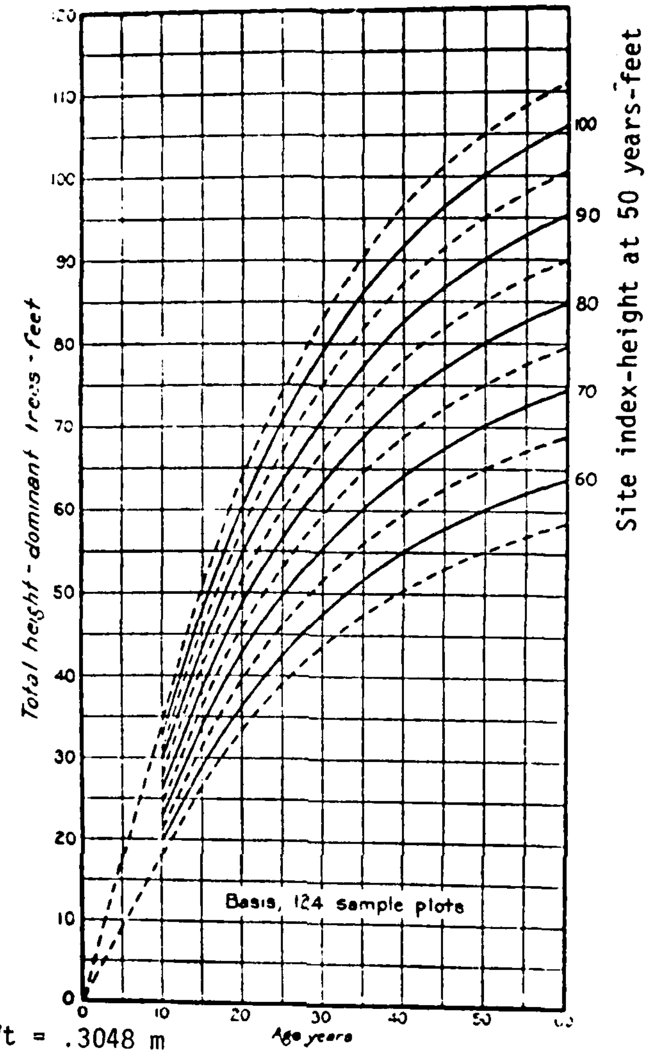
With respect to Unit 4, these soils are suitable for the production of sycamore energy plantations. Data reported for alluvial soils in the Mississippi Delta where inherent productivity is higher indicate that under intensive management, dry weight yields of 2 to 3 tons/acre/year (448,000 to 473,000 $kg/Km^2/yr$) can be expected (Reference 41). With the existing diverse species composition, and the high-graded nature of the stands, growth estimates for the present stands are impractical.

The yields reported in Table E-2 can be appreciably increased by site amelioration practices, as discussed in a subsequent paragraph.

Based on physical soil properties, soil wetness class, and annual precipitation, most of the fee area and most of the surrounding terrain are rated as having moderate to severe equipment limitations or restrictions. The equipment limitation rating indicates the relative degree of restrictions on the duration of the feasible logging period, logging method, or the type of logging equipment utilized. A rating of moderate indicates that logging is restricted during 1 to 3 months of the year; a severe rating indicates restriction for more than three months. These restrictions can, to a large extent, be overcome by the use of specialized logging equipment. The landscape units are rated as follows:

Unit 1 - moderate

Unit 2 - moderate to severe



1 ft = .3048 m

Figure E-1. **Site Index Curves for Slash Pine. From U.S.D.A Miscellaneous Publication 50.**

Unit 3 - severe

Unit 4 - severe

There does exist an area of fee lands within the buffer zone which has little logging restriction. This rather extensive area is located near the old town of Logtown.

The recommended site amelioration practices to improve yields are site preparation and conversion of sulfaquepts. Most of the flatwoods soils are phosphorus deficient. Similar soils across the Southern Region of the U.S. have responded with up to a 220% increase in growth during the early years of the rotation (years from planting to harvest and regeneration) following phosphorus fertilization. It is reported that a

Table E-2. Estimated Productive Potential and Species Suitability for Landscape Units in the NASA Fee Area*.

Unit No.	Site Index Range ft.	Weighted SI ft.	Weighted Growth cds./ac/yr	Weighted Growth bf.ft./ac.yr	Species Recommended
1	80-90	90	2.0	300	slash pine
2	85-95	90	2.0	300	slash pine
3	80-90	83	1.8	270	slash pine
4		No data available			mixed hardwood

*From Soil Conservation Service Reports. For Unmanaged Stands.

15 year old fertilized slash pine plantation with approximately 500 stems per acre contained 101.5 dry tons (92.1×10^3 kg) of total above ground biomass excluding the understory vegetation; bark and branches totaled 21.2 tons (19.2×10^3 kg) (Reference 42). An unfertilized portion of the plantation contained only 23.6 tons (21.4×10^3 kg). The fertilization apparently increased the dry matter yield by approximately 5 tons/ac/yr. It is known, however, that the effects of fertilization are not long term, and that the major growth increases are in the early years after fertilization. A comparison of two 5 year old overstocked slash pine stands indicated that fertilization resulted in an increased total above ground biomass yield of 182%.

Water table control as a site amelioration practice can result in an additional two fold growth increase (Reference 42 and 43). Thus, surface drainage of the wet sites is recommended. This can be accomplished by using a ditching plow to effect an 18 inch (0.44 m) deep V-ditch at 2-1/2 (165 feet or 50 m) intervals. Low, wet flats should, however, receive bedding treatment. Table E-3 indicates recommended practices by soil units.

The areas of Sulfaquepts, approximately 338 acres (1.4 km^2), are presently in a non-productive state. Much of this area can be converted to a productive state by application of lime and by improving surface drainage. In addition, if future canal dredging is anticipated, the lowest, wettest portion of the existing spoil areas should be diked and utilized for the future spoil deposits. Although restricted by the water level of the canal, improved surface drainage can be obtained by a network of V-ditches and improved outlets through the existing levee.

Assuming only a modest 2-1/2 fold increase in fiber production by the use of the recommended practices, and the conversion of 338 acres (1.4 km^2) of Sulfaquepts to a production state, it is estimated that the 8544 acres (34.6 km^2) of pine sites within the fee area can produce approximately

Table E-3. Recommended Site Amelioration Practices by Landscape Units

Unit No.	Acres	km^2	Fertilization Rates N lbs/acre (kg/km^2)	P	Surface Drainage
1	700	2.8	20 (.22)	40 (.45)	No
2	1162	4.7	0	40 (.45)	Yes
3	6344	25.7	0	40 (.45)	Yes
4	730	3.0	Variable		No

54,718 tons (49,639 x 10^3 kg) of dry, merchantable biomass per year; the estimate assumes two cds/ac/yr (0.00049 cd/m^2/yr) for treated Sulfaquept areas. This merchantable volume should yield approximately 13,680 dry tons (12,410 x 10^3 kg) of tops and branches and 12,038 tons (10,921 x 10^3 kg) of roots and stumps per year.

Although soil mapping is not available at this time in the buffer zone, field observation indicates that the relative distribution of landscape units remains similar with the exception of an increase in Unit #1 acres (at Logtown) at the expense of acres in Unit #3. Therefore, estimated acreage by landscape units for the Buffer Zone is: #1-438 acres (1.7 km^2); #2-372 acres (1.5 km^2); #3-1962 acres (7.9 km^2); and #4-86 acres (0.35 km^2). Lands best suited to slash pine total 2772 acres (11 km^2). The annual merchantable yield of dry biomass is estimated to be 18,288 tons (16,591 x 10^3 kg) with an additional 4573 tons and 4023 tons (4148 x 10^3 and 3650 x 10^3 kg) annually in tops and branches, and roots and stumps, respectively.

A composite map of buffer zone holdings was initially used to locate fee lands in the area. A more intensive search of the individual plot sheets was made after acreage discrepancies were noted following the preliminary reports. This search added 532 acres (2.15 km^2) of forested fee lands in the Buffer Zone. Approximately 61% (1.3 km^2) of the additional acreage is located in the Coastal Flatwoods, with the remaining 39% (0.84 km^2) in the Lower Coastal Plain. The soils of the Lower Coastal Plain are better drained than the Flatwoods soils. These more upland sites are predominantly composed of well drained acidic, loamy soils ranging from 0 to 12% in slope. Logging year-round is possible on slopes less than 12%. The potential productivity of these soils is limited to pines except in the small stream bottoms where productivity is good for mixed hardwood species. Bedding and/or surface water drainage is not necessary, and response to fertilization is not as pronounced as in the wetter series. On a small-wood rotation of 25 years, current productivity of 1.5 cds/ac/yr (371 cds/km^2/yr) is estimated, but no data are available for increased productivity due to site amelioration practices.

The total anticipated yield of slash pine using intensive management procedures such as surface drainage, bedding and fertilization is shown in Table E-4.

Table E-4. Estimated Annual Yield of Dry Biomass Under Intensive Management. Pine Sites Sites Only.

Landscape Unit	Fee Area (km^2)[b]	Buffer[c] (km^2)	Total (km^2)	Dry Weight - Tons (kg)[a] Merchantable	Tops	Stumps	Total
1	2.8	1.8	4.6	7,332	1,833	1,613	10,778
2	4.7	1.5	6.2	9,883	2,471	2,174	14,528
3	25.7	7.9	33.6	48,162	12,041	10,596	70,799
Sulfaquepts	1.4	0	1.4	871	218	191	1,280
			45.8	66,248	16,563	14,574	97,385

[a] tons = 1.102 x 10^3 kg

[b] acres = 247 x km^2

[c] Excluding 532 acres (2.2 km^2) of additional forest yielding 1.5 cds/ac/yr (371 cds/km^2/yr).

Although there are no growth and yield data for mixed hardwood stands in the lower Pearl River drainage, it is recognized that plantation-grown sycamore will produce more biomass per acre under intensive management than will the native species mixtures. Based on Southeastern survey data by Smith (Reference 44), yields of plantation-grown sycamore can average about 210 cu ft/ac/yr (951 m^3/km^2/yr) on a 15 year rotation. This yield generally assumes complete initial site preparation with fertilization as dictated by the site, and cultivation during the first several years.

Based upon an average specific gravity of 0.46, and an average weight per cubic foot of 28.7 pounds (445 kg/m^3), the estimated yield in dry tons of biomass for Unit 4 soils is as follows:

	Acres (km^2)	cf/ac/yr ($m^3/km^2/yr$)	dry wt/ct (kg/m^3)	Total Annual Yield dry tons/ac (10^3 kg/m^2)
Fee Area	730	210	28.7#	2200
	(2.9)	(951)	(445)	(0.49)
Buffer Zone	86	210	28.7#	259
	(0.35)	(951)	(445)	(0.06)
Total	816			2459
	(3.25)			(0.55)

Thus, the estimated annual dry biomass production for the NASA fee land is 109,779 tons (99,589 x 10^3 kg).

One element which adds uncertainty to the plantation yields is the level of infection by fusiform rust within slash pine plantations. The potential yields discussed are for sites with an average or less degree of infection. However, on-site visits at NASA, and additional information, suggest that the NASA site may have above average infection by fusiform rust. Fusiform rust kills some trees, makes the stand more susceptible to wind-losses and reduces overall volume yield. In a managed forest actions would be taken to minimize this loss to fusiform rust.

APPENDIX F. SURVEY OF INTEREST IN SUPPLYING ENERGY WOOD FOR NSTL/MSAAP

SURVEY OF INTEREST IN PROVIDING ENERGY WOOD
NASA/ARMY BIOMASS ENERGY STUDY
NATIONAL SPACE TECHNOLOGY LABORATORIES
NSTL STATION, MS 39520

I. REQUIREMENTS AND INFORMATION

A. Energy Wood Needed

Quantity:	70,000 to 8,000 Tons/Yr.
Moisture Content:	50% ot less
Material Sizing:	Mill Residues - Mill run, preferably less than 4"x4"x4" but not more than 20% over 1'X1'X3'
	Logging Residues and Other - Chip Run
	Fines - 50% or less of total material supplied

B. Delivery Point - To Material Storage Area at plant near Building 3204.

C. Transportation Facilities - Water, Rail or Highway

D. Government (NASA) Owned forest lands that could be made available to your Company through a trade agreement for forestry management services and harvesting in return for energy wood - Approximately 12,000 acres. See attached report by Dick Porterfield.

E. Probable duration of agreement mentioned in D. above - Up to 25 years beginning about October 1, 1980.

F. It is desirable to utilize all available energy wood materials from the 12,000 acres of forest lands including tops, limbs, understory, thinnings, culls and possibly roots/stumps.

II. INTEREST QUESTIONS

A. Considering the above requirements and information, would your Company be interested in providing the energy wood? _X_ YES ___ NO

Comments:

The "Yes" indicates a further interest, but is not to be intreprcted as a committment at this time.

April 23, 1979

B. Are the above material sizing requirements acceptable? _X_ YES ___ NO

If not, what sizing requirements would your Company recommend for cost effectivity and/or availability?

Includes sawdust up to whole tree chips

C. What energy wood materials would your company utilize from the 12,000 acres of government forest lands? (Check appropriate items)

_x_ Tops _x_ Limbs ___ Understory ___ Roots/Stumps _x_ Culls

_x_ Thinnings ___ Other - Specify

D. Would your Company provide energy wood from the same materials as checked above from your forest lands in the NSTL area?
_X_ YES ___ NO

Comments:

E. What would be your preferred mode of transporting biomass feedstock considering availability and transportation cost?

_X_ Water ___ Rail _X_ Highway

F. Duration of Trade Agreement required by your Company? _6_ Years

Estimated life of a whole tree chipper job

G. What is your estimated cost per acre for providing Forestry Management services on the 12,000 acres of NASA owned forest lands? $___________ - No charge for the Management Plan. Charge for cultural work at cost per attached schedule.

H. What is your best estimate of the cost per ton for the energy wood described above delivered to NSTL?

1. Present Time - $16.82
2. October 1, 1980 - $18.50

April 23, 1979

I. What basis and rate would you recommend for determining the escalation in the price of energy wood for the next 10-20 years? Please explain.

8% to 10% per year based on past three years escalation plus stumpage value increase resulting from increased fiber demand.

J. What is your estimate of the ratio for trading energy wood for merchantible bole on NASA owned lands, including your forestry management and harvesting services?

1 Tons of Energy Wood divided by 2.3 Tons of merchantible bole = Ratio

This estimated ratio is based on tables covering average timber in an average stand, but it could vary up or down depending on stand quality and market values.

K. Other Comments, Suggestions or Recommendations:

We express an interest in assisting NASA with land management of the 12,000 acres of timber through our Landowner Assistance Program even without an agreement on energy wood.

L. Company: International Paper Company
Address: Woodlands Department
P. O. Box 311, Natchez, Ms. 39120
Representative: ____
Title: ____

J. L. Ward
Regional Manager

May 29, 1979

115 - Landowners Assistance Program February 27, 1979

Area Superintendents
Mr. Donald A. Whitmer

Attached is schedule, 1979 Standard Equipment and Labor Costs Per Day, for use in determining agreement prices to be charged landowners for services provided by International Paper Company in LAP agreements.

These rates were established on equipment furnished by Mobile and represent costs for full eight-hour day activity.

If any additional copies are needed for further distribution to field personnel, let us know.

Charles B. Adams
Controller

GBP/ls

Attachment

bcc: GBP
WBD
Acctg.
CF
RF

1979 STANDARD EQUIPMENT AND LABOR COSTS PER DAY

(For Use in Determining Agreement Price Which Will be Charged to Landowners for Services Provided by IPCo. in LAP Agreements)

	Rates Per Eight Hour Day						
	Equipment Cost						
	16.67% Depreciation $	Maint. Cost $	Fuel & Lube $	Total Equip. Cost $	Labor $	Co. Paid Benefits $	Total Cost Per Day $
Crawler Tractors							
Size 3-less winch	23.34	16.34	16.19	55.87	50.72	14.20	120.79
Size 4 w/winch	49.18	34.43	25.15	108.76	50.72	14.20	173.68
Size 6 w/winch	80.02	56.01	39.07	175.10	50.72	14.20	240.02
Size 8 w/winch	145.86	102.10	69.23	317.19	50.72	14.20	382.11
Motor Graders							
120 H.P. Minimum	55.84	39.09	39.58	134.51	50.72	14.20	199.43
130 H.P. Minimum	63.35	44.35	44.53	152.23	50.72	14.20	217.15
Front End Gravel Loaders							
2¼ Cu. Yds.	44.18	30.93	39.07	114.18	50.72	14.20	179.10
3 Cu. Yds.	63.35	44.35	44.64	152.34	50.72	14.20	217.26
Lowboy Truck Tractors							
25 Ton - Single Axle	25.84	18.09	76.57	120.50	50.72	14.20	185.42
35 Ton - Tandem Axle	35.01	24.51	103.29	162.81	50.72	14.20	227.73
50 Ton - Tandem Axle	57.51	40.26	130.00	227.77	50.72	14.20	292.69
Harrows							
Disc - Rome TRH 20-30	11.67	8.17	-	19.84	-	-	19.84
Bedding	7.50	52.55	-	60.05	-	-	60.05
Root Rakes							
D-6	4.58	3.21	-	7.79	-	-	7.79
D-7	6.42	4.49	-	10.91	-	-	10.91
D-8	7.50	5.25	-	12.75	-	-	12.75

1979 STANDARD EQUIPMENT AND LABOR COSTS PER DAY

(For Use in Determining Agreement Price Which Will be Charged to Landowners for Services Provided by IPCo. in LAP Agreements)

	Rates Per Eight Hour Day						
	Equipment Cost						
	16.67% Depreciation $	Maint. Cost $	Fuel & Lube $	Total Equip. Cost $	Labor $	Benefits $	Total Cost Per Day $
V-Blades							
D6C	11.67	8.17	-	19.84	-	-	19.84
D7F	13.34	9.34	-	22.68	-	-	22.68
D8K	15.00	10.50	-	25.50	-	-	25.50
KG Blades							
Size 6	4.42	3.09	-	7.51	-	-	7.51
145 Size 7	6.67	4.67	-	11.34	-	-	11.34
Size 8	8.34	5.84	-	14.18	-	-	14.18
Planters							
3 Point Hitch	3.33	2.33	-	5.66	-	-	5.66
Single Crank	5.00	3.50	-	8.50	-	-	8.50
Double Crank	5.25	3.68	-	8.93	-	-	8.93
Rolling Choppers							
Single 10'	14.17	9.92	-	24.09	-	-	24.09
Single 12'	16.67	11.67	-	28.34	-	-	28.34
Tandem 7'	17.50	12.25	-	29.75	-	-	29.75
Tandem 10'	25.01	17.51	-	42.52	-	-	42.52
Fire Plow - Single Crank Axle	3.75	2.63	-	6.38	-	-	6.38
Sprayer - Skid Type 60 GPM/800 PSI w/600 Gal. Tank - 60 H.P. Engine	5.92	4.14	8.48	18.54	-	-	18.54
Sprayer - Skid Type 50 GPM/800 PSI w/600 Gal. Tank - 37 H.P. Engine	4.58	3.21	12.72	20.51	-	-	20.51

1979 STANDARD EQUIPMENT AND LABOR COSTS PER DAY

(For Use in Determining Agreement Price Which Will be Charged to Landowners for Services Provided by IPCo. in LAP Agreements)

	Rates Per Eight Hour Day						
	Equipment Cost						
	16.67% Depreciation $	Maint. Cost $	Fuel & Lube $	Total Equip. Cost $	Labor $	Benefits $	Total Cost Per Day $
Dump Truck - 6 Yd.	15.84	11.09	67.67	94.60	42.20	11.82	148.62
Front Mounted Plow	4.17	2.92	-	7.09	-	-	7.09
Backhoe - 3/4 Cu. Yd.	66.68	46.68	30.72	144.08	42.20	11.82	198.10
Trucks							
Stake Body - 2½ Ton	13.34	9.34	32.57	55.25	42.20	11.82	109.27
Crew Cab Pickup - 3/4 Ton	5.58	3.91	17.73	27.22	38.88	10.89	76.99
Pickup - ½ Ton	4.50	3.15	16.49	24.14	38.88	10.89	73.91

April 23, 1979

SURVEY OF INTEREST IN PROVIDING ENERGY WOOD
NASA/ARMY BIOMASS ENERGY STUDY
NATIONAL SPACE TECHNOLOGY LABORATORIES
NSTL STATION, MS 39520

I. REQUIREMENTS AND INFORMATION

A. Energy Wood Needed

Quantity:	70,000 to 80,000 Tons/Yr.
Moisture Content:	50% or less
Material Sizing:	Mill Residues - Mill run, preferably less than 4"x4"x4" but not more than 20% over 1'X1'X3'
	Logging Residues and Other - Chip Run
	Fines - 50% or less of total material supplied

B. Delivery Point - To Material Storage Area at plant near Building 3204.

C. Transportation Facilities - Water, Rail or Highway

D. Government (NASA) Owned forest lands that could be made available *to your Company* through a trade agreement for forestry management services and harvesting in return for energy wood - Approximately 12,000 acres. See attached report by Dick Porterfield.

E. Probable duration of agreement mentioned in D. above - Up to 25 years beginning about October 1, 1980.

F. It is desirable to utilize all available energy wood materials from the 12,000 acres of forest lands including tops, limbs, understory, thinnings, culls and possibly roots/stumps.

II. INTEREST QUESTIONS

A. Considering the above requirements and information, would your Company be interested in providing the energy wood? ✓ YES ___ NO

Comments:

April 23, 1979

B. Are the above material sizing requirements acceptable? ✓ YES ___ NO

If not, what sizing requirements would your Company recommend for cost effectivity and/or availability?

C. What energy wood materials would your company utilize from the 12,000 acres of government forest lands? (Check appropriate items)

✓ Tops ✓ Limbs ✓ Understory ___ Roots/Stumps ✓ Culls

✓ Thinnings ___ Other - Specify

D. Would your Company provide energy wood from the same materials as checked above from your forest lands in the NSTL area?
✓ YES ___ NO

Comments:

E. What would be your preferred mode of transporting biomass feedstock considering availability and transportation cost?

___ Water ✓ Rail ✓ Highway

F. Duration of Trade Agreement required by your Company? 10+ Years

G. What is your estimated cost per acre for providing Forestry Management Services on the 12,000 acres of NASA owned forest lands? $__________ would this included site prep & planting?

H. What is your best estimate of the cost per ton for the energy wood described above delivered to NSTL?

1. Present Time - $20

2. October 1, 1980 - $22

April 23, 1979

I. What basis and rate would you recommend for determining the escalation in the price of energy wood for the next 10-20 years? Please explain.

FUEL OIL PRICE INDEX ADJUSTED QUARTERLY

J. What is your estimate of the ratio for trading energy wood for merchantible bole on NASA owned lands, including your forestry management and harvesting services?

80,000 Tons of Energy Wood divided by 12,800 Tons of Merchantible Bole = 6.25 Ratio

K. Other Comments, Suggestions or Recommendations:

THESE ANSWERS ARE UNAUDITED AND SUBJECT TO ADDITIONAL INFORMATION

L. Company ST. REGIS PAPER CO.
Address MONTICELLO, MS.
Representative Robert D. Holland
Title Chip Mill Manager

APPENDIX G. AN ENERGY WOOD HARVESTING SYSTEM FOR NSTL/MSAAP

There are two requirements that must be met by the harvesting system. In order to maximize the biomass yield from NSTL fee lands, trees down to one inch (.0254 m) DBH must be harvested. The system must be usable for both thinnings and complete harvesting operations. The annual tonnage to be harvested will approach 20,000 tons (18×10^6 kg) initially and increase to some 168,000 tons (152×10^6 kg) in 26 years. In order to achieve these annual tonnages the daily production rates must be as follows:

Operating days per year	Year 1, tons (10^3 kg) per day	Year 26, tons (10^3 kg) per day
210	93.4 (84.7)	797.3 (723.8)
220	89.1 (80.8)	761.6 (690.9)
230	85.3 (77.4)	728.5 (660.9)
240	81.7 (74.1)	698.2 (633.4)

Most harvesting operations use 240 days per year in their calculations. A 220 operating day/year is more realistic for NSTL considering the rainfall patterns and ground conditions common to the area. When material over 10 inches (.254 m) DBH must be harvested, the whole-tree system was recommended in the MITRE Study and the feasibility of using such a system for a full range of diameters down to 1.0 inch DBH class was a firm conclusion of a North Carolina study (Reference 45).

Compared in Table G-1 are the cost of a number of alternative harvesting methods as they are affected by DBH. The cost quoted are 1977 prices. The total cost per cord, both overhead and operating, are highest for small diameter materials. All systems are sensitive to DBH changes. As shown, whole-tree chipping compares very favorably at any particular DBH class. A complete cost analysis of each of these alternative harvesting systems when harvesting 6 to 7 inch (0.15 to 0.18 m) DBH timber is included at the end of this Appendix (Reference 45). However, it is the volume of material to be harvested that is important in determining which harvesting system is most economical. The investment cost of eight logging systems are shown in Table G-2. As can be seen, the investment cost for WTC is substantially more than any of the other systems. However, the annual production from a whole tree chipping system is nearly twice as high as the system with second highest production. These costs spread over many more cords, reduces the impact of the high initial investment. The variable operating cost per cord is only $13.11 of the $22.16 shown for whole-tree chipping in the table.

Once whole-tree chipping was selected as the most efficient harvesting system, an actual operation currently harvesting a daily tonnage in the range of the initial amount to be harvested on the NSTL site was located and actual data obtained. The system included an 18 inch (0.46 m) throat diameter chipper, 1 feller buncher, 1 grappler skidder, 1 tractor truck and 5 chip vans. This system was small for a whole-tree chipping system and the investment cost was only about one-half the extimated cost of $571,875. Although production from thinning operations was 80 tons (73×10^3 kg), the potential daily capacity for this operation could

Table G-1. Cost Per Cord Comparisons by DBH and Logging Systems

DBH	Chain Saw Bob Truck	Chain Saw Pallets	Chain Saw Prehauler	Chain Saw Cable Skidder	Feller/Buncher Delimbing Gate	Short Wood Prehauler	Lg.Wd.Har. Grapple Skidder	WTC
4	$32.56	$34.19	$32.77	$59.11	$28.18	$70.98	$35.94	$30.95
5	26.70	28.46	27.40	42.22	26.80	51.48	27.94	24.59
6	23.68	25.62	24.07	32.80	21.96	34.22	24.28	22.45
7	21.75	23.80	21.93	25.23	19.05	27.40	22.16	21.76
8	20.60	22.71	20.68	20.19	19.89	26.38	19.13	20.13
9	19.97	22.11	20.03	20.24	18.11	23.16	18.57	18.96
10	19.60	21.75	19.70	18.00	16.77	20.90	17.16	18.59

Table G-2. Comparison of Investment Costs by Logging Systems

Logging Systems	Total Investment	Cords Per Year	Investment Per Annual Cord	Cost per Cord 0.15 to 0.18 m DBH
Chain Saw-Bob Truck	$ 17,050.	2,000	$ 8.52	$24.61
Chain Saw-Pallets	59,760.	5,040	11.86	23.66
Chain Saw-Prehauler	79,850.	6,000	13.31	23.98
Chain Saw-Cable Skidder	149,900.	4,800	31.23	31.14
Feller Buncher-Delimbing Gate	251,975.	12,000	21.00	21.71
Shortwood Harvester-Prehauler	167,975.	6,000	28.00	28.75
Longwood Harvester-Grapple Skidder	241,875.	9,600	25.19	21.55
Whole Tree Chips	571,875.	23,760	24.07	22.16

Equipment and labor balanced to cut small timber between 6.0 and 7.0 inches (0.15 to 0.18 m) DBH.

be 160 tons (145 x 10^3 kg) if more chip vans were available. A whole tree chipping system similar to this operation would be adequate to begin operations on the NSTL site and would have relatively low harvesting costs. A large chipper with a 22 inch (.56 m) throat diameter should be purchased and auxiliary or support equipment should be added as needed. The chipper would have a capacity of 40 tons per hour (36 x 10^3 kg/hr) and would not be the limiting volume factor during its useful life. The existing NSTL road network is well located and in good condition for facilitating whole-tree chipping. Labor costs with the whole-tree chipping system will be relatively low compared to other timber harvesting systems, however the skill of the labor force must be much higher than the current level being utilized in this area. Perhaps new equipment and additional training will be needed.

Current Mississippi producers seem largely unable to deliver large quantities of wood in a reliable manner. Multiple small operations could supply large quantities of wood. Regardless of utilization standards, harvesting efficiency for small operations are very poor. Appreciable organizational skill would be required to insure a continuous and sufficient quantity of wood. Pulp mills avoid these problems by using more producers than needed, all producing less than their potential, and by giving quotas to producers in times of sufficient supply. The NSTL site would not generate the large volumes of wood necessary for this approach. However, these limitations must be considered in the formation and supervision of a dependable harvesting operation on the NSTL site.

The system selected for harvesting the NSTL forest, whole-tree, in-woods chipping, is an advanced harvesting system. This fact is ovbious from the census of pulpwood producers since no whole-tree chippers were identified in Mississippi in 1976 and very few were in operation across the South. Yet the whole-tree system has been tested and the feasibility of harvesting wood for energy on the NSTL site does not depend on emerging technology.

An emerging biomass harvesting system which is even more intensive and mechanized than the whole-tree chipping system is the mobile chipper-retriever. This mobile chipper-retriever was conceptualized by Peter Koch a Pineville, LA. The advantages of this system include the the elimination of some of the felling-bunching, prehauling and skidding operations of the whole-tree chipping system, and a potential improvement in the total biomass yield since the system moves over the entire site. Development of the machine is progressing and several industrial forestry concerns are contributing to its development (Reference 46). If the development continues to progress, the mobile chipper-retriever may be available for harvesting the higher volumes from the NSTL lands in the future years. It could be used to harvest material from the natural existing stands and the whole-tree chipper could be shifted to the plantations being thinned. Without question, the conceptualized system has a utilization efficiency compatible to the objectives of the energy from biomass program on NSTL lands. The approximate cost of this emerging system is unknown.

There are few whole-tree chipping operations in existence and most of the ones in operation are too large for initial needs of the NSTL/MSAAP program. For example, the operation studied by Tufts (Reference 47) included the following equipment:

- 2 Feller bunchers
- 1 Chainsaw
- 3 Grapple Skidders
- 1 Field chipper
- 4 Trucks
- 6 Van trailers
- 1 Bulldozer
- 1 Welder
- 2 Pickups

The capacity was approximately 270 tons (245×10^3 kg) per day. Another operation studied by Deal (Reference 46) included:

- 1 Feller buncher
- 3 Grapple Skidders
- 1 Field chipper
- 3 Chainsaws
- 1 Hydraulic loader (sawtimber was not chipped)
- 1 Used set out truck
- 1 Equipment moving truck
- 1 Lowboy trailer
- 1 Crew bus
- 1 Pickup

(van trailers not included in analysis)

The capacity of this system was 210 tons (190×10^3 kg) per day plus 27 MBF (Doyle Rule) of sawtimber. Field chipper capacity can be as high as 500 tons (454×10^3 kg) per day using one of today's large in-woods chippers.

The actual on-going whole-tree chipping operation identified earlier was utilized primarily for thinning operations and this naturally reduces the daily capacity. Although currently production is 80 tons (73×10^3 kg) per day, the total capacity of the system is over 150 tons (136×10^3 kg) per day in a clear-felling operation. Equipment included:

- 1 18-inch field chipper
- 1 Feller buncher
- 1 Grapple skidder
- 1 Tractor truck
- 5 Chip vans

Total original cost of the system was estimated to be $250,000. A harvesting system similar to this actual operation should be adequate during the early years of the energy from wood program.

A system equipped to meet the site conditions specific to NSTL is described in the text of this report. The 22-inch field chipper specified has more than adequate capacity and will be able to handle the occasional large cull hardwoods found on the NSTL site. All skidders should be equipped with oversized tires to assure good flotation during wet periods. The shear price quoted in Table 16 has a 20-inch (0.508 m) capacity. This will necessitate felling some of the largest trees with a chainsaw but a bigger shear head would be uneconomic for the large amount of small diameter material. Chip vans should have a 20 to 25 ton (18 to 23 x 10^3 kg) capacity.

Listed at the end of this Appendix are the names of harvesting equipment suppliers, harvesting consultants and harvesting contractors who supplied information for this study.

STUMP TO STUMP LOGGING
5 CORD TANDEM BOB TRUCK

EQUIPMENT	ORIGINAL COST	LIFE	RESIDUAL VALUE	ANNUAL DEPRECIATION	APBI*	OPERATING COSTS
2 Chain Saws	$ 750.	1 yr.	$ 150.	$ 600.	$ 750.	$ 9.00/day
1 Truck	10,000.	3 yrs.	2,500.	2,500.	7,500.	.16/mile
1 Big Stick Loader	1,500.	3 yrs.	300.	400.	1,100.	3.00/day
1 Pickup Truck	4,800.	3 yrs.	1,200.	1,200.	3,600.	10.00/day
TOTALS	$17,050.		$4,150.	$4,700.	$12,950.	

*Annual Profit Bearing Investment = $\frac{(I-R)n + 1}{2N} + R$ Where: I is initial cost
R is residual value
N is life of equipment in yrs.

	ANNUAL OVERHEAD COSTS
Depreciation	$ 4,700.00
Interest, Taxes & Minor Ins.,15% of APBI	1,942.50
Truck Ins., Use Taxes, Registration	1,200.00
Bookkeeping Expense	360.00
Legal Fees	360.00
Office Expense	100.00
Total Overhead Cost	$ 8,662.50

Annual Working Days - 200

Overhead Cost per Day	$ 43.31
Labor 4 men @ $3.00/hr. for 10 hr. day	132.00
Operating cost $22.00 plus 200 miles @ $0.16/mile	54.00
Total Daily Cost	$ 229.31
Cost per cord at 10 cords per day	$ 22.93
Workmen's Compensation Insurance	1.68
Total Cost per Cord	$ 24.61

PALLET LOGGING

(7CORD TANDEM AXLE TRAILER)

EQUIPMENT	ORIGINAL COST	LIFE	RESIDUAL VALUE	ANNUAL DEPRECIATION	APBI	OPERATING COSTS
4 Chain Saws	$ 1,500.	1 yr.	$ 300.	$ 1,200.	$ 1,500.	$ 18.00/day
1 Tractor	30,000.	5 yrs.	5,000.	5,000.	20,000.	35.00/day
1 Big Stick Loader	1,500.	5 yrs.	0	300.	900.	6.00/day
12 Pallets	2,160.	5 yrs.	360.	360.	1,440.	3.00 day
1 Truck	12,000.	3 yrs.	2,400.	3,200.	8,800.	.23/mile
1 Pallet Trailer	7,200.	5 yrs.	1,700.	1,100.	5,000.	.05/mil
1 Pickup	4,800.	3 yrs.	1,200.	1,200.	3,600.	10.00/day
Misc. Tools	600.	3 yrs.	0	200.	400.	1.00/day
TOTALS	$59,760.		$10,960.	$12,560.	$41,640.	

	ANNUAL OVERHEAD COSTS
Depreciation	$ 12,560.00
Interest, Taxes & Minor Ins.,15% of APBI	6,246.00
Truck Ins.,Registration & Use Tax	2,000.00
Bookkeeping Expense	360.00
Legal Fees	360.00
Office Expense	100.00
Total Overhead Cost	$ 21,626.00

Annual Working Days - 240

Overhead Cost per day	$ 90.11
Labor 4 men @ $3.00/hr - 10 hr. day 2 men @ $3.75/hr - 10 hr. day	214.50
Operating Costs $73.00 plus 300 x .28	157.00
Total Daily Cost	$ 461.61
Cost per cord at 21 cords per day	$ 21.98
Workmen's Compensation Insurance	1.68
Total Cost per cord	$ 23.66

CHAIN SAW & PREHAULER - 10 CORD TRUCK TRAILER LOAD

EQUIPMENT	ORIGINAL COST	LIFE	RESIDUAL VALUE	ANNUAL DEPRECIATION	APBI	OPERATING COSTS
6 Chain Saws	$ 2,250.	1 yr.	$ 450.	$ 1,800.	$2,250.	$27.00/day
1 Prehauler	27,000.	3 yrs.	6,000.	7,000.	20,000.	36.00/day
1 Truck	32,000.	5 yrs.	5,333.	5,333.	21,333.	.28/mile
2 Trailers	13,200.	6 yrs.	2,400.	1,800.	8,700.	.05/mile
1 Pickup	4,800.	3 yrs.	1,200.	1,200.	3,600.	10.00/day
Misc. Tools	600.	3 yrs.	- -	200.	400.	1.00/day
TOTALS	$79,850.		$15,383.	$17,333.	$56,283.	

	ANNUAL COST
Depreciation	$17,333.00
Interest, Minor Taxes, Ins., 15% of APBI	8,442.45
Truck Insurance, Use Tax & Registration	2,300.00
Bookkeeping Expense	360.00
Legal Fees	360.00
Office Expense	100.00
TOTAL	$ 28,895.45

Annual Working Days - 240

Overhead Cost per day		$ 120.40
Labor 6 men at $3.00/hr - 10 hr. day	$198.00	
2 men at $3.75/hr - 10 hr. day	82.50	
		280.50
Operating Cost per day $74 + 250 miles @ .33		156.50
Total Daily Costs		$ 557.40
Cost per cord @ 25 cords per day		$ 22.30
Workmen's Compensation Insurance		1.68
Total Cost per Cord		$ 23.98

CHAIN SAW AND CABLE SKIDDER

EQUIPMENT	ORIGINAL COST	LIFE	RESIDUAL VALUE	ANNUAL DEPRECIATION	APBI	OPERATING COSTS
4 Chain Saws	$ 1,500.	1 yr.	$ 300.	$ 1,200.	$ 1,500.	$18.00/day
2 Skidders	80,000.	5 yrs.	15,000.	13,000.	54,000.	64.00/day
1 Log Loader	24,000.	5 yrs.	4,000.	4,000.	16,000.	.625/cord
1 Truck	32,000.	5 yrs.	5,333.	5,333.	21,333.	.28/mile
1 Trailer	6,600.	6 yrs.	1,200.	900.	4,350.	.06/mile
1 Pickup	4,800.	3 yrs.	1,200.	1,200.	3,600.	10.00/day
Misc. Tools	1,000.	3 yrs.	- -	333.	667.	1.00/day
TOTALS	$149,900.		$27,033.	$25,966.	$101,450.	

	ANNUAL OVERHEAD COST
Depreciation	$25,966.00
Interest, Taxes & Minor Ins.,15% of APBI	15,217.50
Truck Ins., Use Tax and Registration	2,300.00
Bookkeeping Expense	360.00
Legal Fees	360.00
Office Expense	100.00
Total Overhead	$44,303.50

Annual Working Days - 240

Overhead Cost per day	$ 184.60
Labor - 2 men @ $3.00/hr. - 10 hr. day 4 men @ $3.75/hr.- 10 hr. day	231.00
Operating Cost per Day $93.00 plus 20(.625) plus .34 x 200	173.50
Total Daily Cost	$ 589.10
Cost per cord at 20 cords per day	$ 29.46
Workmen's Compensation Insurance	1.68
Total Cost per Cord	$ 31.14

FELLER BUNCHER - DELIMBING GATE

EQUIPMENT	ORIGINAL COST	LIFE	RESIDUAL VALUE	ANNUAL DEPRECIATION	APBI	OPERATING COSTS
1 Feller Buncher	$42,000.	3 yrs.	$ 6,000.	$12,000.	$30,000.	$ 65.00/day
1 Chain Saw	375.	1 yr.	75.	300.	375.	1.00/day
2 Grapple Skidders	95,000.	5 yrs.	20,000.	15,000.	65,000.	110.00/day
1 Log Loader	24,000.	5 yrs.	4,000.	4,000.	16,000.	.625/cord
1 Delimbing Gate	1,000.	5 yrs.	0	200.	600.	2.00/day
2 Trucks	64,000.	5 yrs.	10,667.	10,667.	42,667.	.28/mile
3 Trailers	19,800.	6 yrs.	3,600.	2,700.	13,050.	.06/mile
1 Pickup	4,800.	3 yrs.	1,200.	1,200.	3,600.	10.00/day
Misc. Tools	1,000.	3 yrs.	0	333.	667.	1.00/day
TOTALS	$251,975.		$45,542.	$46,400.	$171,959.	

	ANNUAL OVERHEAD COST
Depreciation	$ 46,400.00
Interest, Taxes, Minor Ins., 15% of APBI	25,793.85
Truck ins., Use Tax and Registration	4,600.00
Bookkeeping Expense	360.00
Legal Fees	360.00
Office Expense	100.00
Total Overhead	$ 77,613.85
Annual Working Days - 240	
Overhead Cost per Day	$ 323.39
Labor - 6 men - 10 hr. day - $3.75/hr.	247.50
Operating Cost per day $189.00 plus .34(600) plus 60 (.625) =	430.50
Total Daily Cost	$ 1,001.39
Cost per cord at 50 cords per day	$ 20.03
Workmen's Compensation Insurance	1.68
Total Cost per Cord	$ 21.71

SHORT WOOD HARVESTER & PREHAULER

EQUIPMENT	ORIGINAL COST	LIFE	RESIDUAL VALUE	ANNUAL DEPRECIATION	APBI	OPERATING COSTS
2 Harvesters	$90,000.	3 yrs.	$12,000.	$26,000.	$64,000.	$120.00/day
1 Chain Saw	375.	1 yr.	75.	300.	375.	1.00/day
1 Prehauler	27,000.	3 yrs.	6,000.	7,000.	20,000.	36.00/day
1 Truck	32,000.	5 yrs.	5,333.	5,333.	21,333.	.28/mile
2 Trailers	13,200.	6 yrs.	2,400.	1,800.	8,700.	.05/mile
1 Pickup	4,800.	3 yrs.	1,200.	1,200.	3,600.	10.00/day
Miscellaneous Tools	600.	3 yrs.	- -	200.	400.	1.00/day
TOTAL	$167,975.		$27,008.	$41,833.	$118,408.	

	ANNUAL OVERHEAD COST
Depreciation	$ 41,833.00
Interest, taxes & minor ins., 15% of APBI	17,761.20
Truck insurance, use tax & registration	2,300.00
Bookkeeping Expense	360.00
Legal Fees	360.00
Office Expense	100.00
Total Overhead	$ 62,714.20

Annual Working Days - 240	
Overhead Cost per day	$ 261.31
Labor - 4 men - 10 hr. day - $3.75/hr.	165.00
Operating Cost per Day - $168.00 plus 250 miles @ $0.33	250.50
Total Daily Costs	$ 676.81
Cost per cord @ 25 cords per day	$ 27.07
Workmen's Compensation Insurance	1.68
Total Cost per Cord	$ 28.75

LONG LENGTH HARVESTER

EQUIPMENT	ORIGINAL COST	LIFE	RESIDUAL VALUE	ANNUAL DEPRECIATION	APBI	OPERATING COSTS
1 Harvester	$87,000.	5 yrs.	$12,000.	$15,000.	$57,000.	$100.00/day
1 Chain Saw	375.	1 yr.	75.	300.	375.	1.00/day
1 Grapple Skidder	47,500.	5 yrs.	10,000.	7,500.	32,500.	55.00/day
1 Log Loader	24,000.	5 yrs.	4,000.	4,000.	16,000.	.625/cord
2 Trucks	64,000.	5 yrs.	10,667.	10,667.	42,667.	.28/mile
2 Trailers	13,200.	6 yrs.	2,400.	1,800.	8,700.	.06/mile
1 Pickup	4,800.	3 yrs.	1,200.	1,200.	3,600.	10.00/day
Misc. Tools	1,000.	3 yrs.	- -	333.	667.	1.00/day
TOTALS	$241,875.		$40,342.	$40,800.	$161,509.	

	ANNUAL OVERHEAD COST
Depreciation	$ 40,800.00
Interest, Taxes, Minor Ins., 15% of APBI	24,226.35
Truck Ins., Use Tax and Registration	4,600.00
Bookkeeping Expense	360.00
Legal Fees	360.00
Office Expense	100.00
TOTAL OVERHEAD	$ 70,446.35

Annual Working Days - 240	
Overhead Cost per Day	$ 293.53
Labor 1 man @ $4.50/hr. 3 men @ $3.75/hr - 10 hr. day	173.25
Operating Cost per day $167.00 plus 40 (.625) plus .34 (400)	328.00
TOTAL DAILY COST	$ 794.78
Cost per Cord at 40 cords per day	$ 19.87
Workmen's Compensation Insurance	1.68
TOTAL COST PER CORD	$ 21.55

WHOLE TREE CHIPS

EQUIPMENT	ORIGINAL COST	LIFE	RESIDUAL VALUE	ANNUAL DEPRECIATION	APBI	OPERATING COSTS
2 Feller Bunchers	$84,000.	3 yrs.	$12,000.	$24,000.	$60,000.	$130.00/day
1 Chain Saw	375.	1 yr.	75.	300.	375.	1.00/day
3 Grapple Skidders	142,500.	5 yrs.	30,000.	22,500.	97,500.	165.00/day
1 Field Chipper	106,000.	5 yrs.	16,000.	18,000.	70,000.	110.00/day
4 Trucks	128,000.	5 yrs.	21,332.	21,334.	85,333.	.28/mile
6 Van Trailers	72,000.	6 yrs.	12,000.	10,000.	48,000.	.07/mile
1 Bulldozer	30,000.	5 yrs.	5,000.	5,000.	20,000.	10.00/day
1 Welder	2,400.	5 yrs.	400.	400.	1,600.	2.00/day
2 Pickups	9,600.	3 yrs.	2,400.	2,400.	7,200.	20.00/day
Misc. Tools	2,000.	3 yrs..	--	666.	1,333.	2.00/day
TOTAL	$571,875.		$99,207.	$104,600.	$391,341.	

	ANNUAL OVERHEAD COST
Depreciation	$104,600.00
Interest, Taxes, Minor Inc.,15% of APBI	58,701.15
Truck Ins.,Use Tax and Registration	9,200.00
Bookkeeping Expense	1,200.00
Legal Fees	1,200.00
Office Expense	300.00
Total Overhead	$175,201.15

Annual Working Days - 240	
Overhead Cost per day	$ 730.00
Labor - 1 Foreman - $1200/month	60.00
10 men @ $3.75/hr - 10 hr. day	412.50
Operating Cost per day $440.00 plus 1100 mi. @ $0.35	825.00
Total Daily Cost	$ 2,027.50

Cost per cord at 99 cords per day	$ 20.48
Workmen's Compensation Insurance	1.68
Total Cost per cord	$ 22.16

Harvesting Equipment

Equipment/Supplier	Contact	Phone No.
1. Feller Buncher Shear		
Morbark Industries, Inc.	Jim Muterspaugh	(517) 866-2381
2. Grapple Skidder		
Morbark Industries, Inc.	Jim Muterspaugh	(517) 866-2381
3. Whole Tree Chipper		
Morbark Industries, Inc.	Jim Muterspaugh	(517) 866-2381
Precision Tree Chipper	Stu Young	(205) 640-5181
4. Tree Puller		
Rome Industries	Sam Coughran	(404) 748-4450
Vermeer Manufacturing Co.	Kevin Groomes	(515) 628-3141
5. Roots/Stumps Extraction/Chipper		
L. B. Foster Co.	Al Herz	(412) 279-8760
6. Complete Residual Biomass Harvester	T. William Nicholson	(206) 682-2752
Nicholson Manufacturing Co.		

Harvesting Consultants

1. Dr. Richard Porterfield
   Mississippi State University

2. Mr. Frank Miller
   Assistant to Dr. R. Porterfield

3. Dr. Peter Koch (318) 445-6511 X-361
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4. Lawrence E. Lassen (504) 589-6787
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5. Bruce A. Macko (Harvest Levels & Reforestation Practice)
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   Forest Products Technologist-Southeastern Area
   U.S. Forest Service
   920 Milner Bldg.
   Jackson, Mississippi 39201

8. Oscar C. Tissue, Jr. (601) 354-7124
   Utilization and Marketing Forester
   908 Robert E. Lee Bldg.
   Jackson, Mississippi 39201

Wood Harvesting Contractors in

the Mississippi Area

1. Lindsey West (601) 426-6927
   West Brothers
   P. O. Box 1351
   Laurel, Mississippi 39440

2. Joseph D. Ball (601) 832-6417
   Route 2
   P. O. Box 158
   Sawcier, Mississippi 39574

3. Gerald Miller (601) 928-7288
   J. S. Miller Lumber Co.
   P. O. Box 36C
   Wiggins, Mississippi 39577

4. Thad or Charles Davis (601) 928-4848
   Davis Brothers
   315 Border Dr.
   Wiggins, Mississippi 39577

APPENDIX H. BIOMASS SYSTEMS FOR HTHW, HTHW AND ELECTRIC POWER AND STEAM PROCESS DESCRIPTIONS AND EQUIPMENT LISTS

This appendix includes the lists of major processing equipment required for the NSTL Biomass Hot Water Plant, the NSTL/MSAAP Biomass Hot Water and Co-generated Electric Power Plant and the MSAAP Biomass Steam Plant. Also included are descriptions of some of the functional sections of these plants. These descriptions are not complete since they are intended to augment the information presented in the text.

NSTL Biomass Hot Water Process Description

Front End Wood Handling System

Energy Wood feed for the steam generators is unloaded from trailers containing about 25 tons (22.7 x 10^3 kg) per load at the trailer dumper (A-1). The dumper unloads the trailers into a hopper having a capacity of about 30 tons (27.2/10^3 kg). The dumper has the capacity for unloading about five to six trailers per hour or a rate of 125 TPH (113.4 x 10^3 kg/hr). The wood chips and fines are unloaded from the hopper via a live bottom feeder and conveyed to the wood receiving conveyor (L-1). The wood receiving conveyor feeds an electromagnetic separator (S-1) where metal objects can be removed from the wood chips. The wood is then fed to the overs disc screen (S-2) where the oversized material is separated. The overs disc screen passes material three inches (7.6 cm) or less to the hogged wood discharge belt conveyor (L-2) for delivery to the wood pile. The oversized material, three inches (7.6 cm) or greater, is fed from S-2 to the wood hogger (A-2) where the material is reduced to nominal three inches (7.6 cm) size. The hogger has a capacity of about 25 TPH (33.7 x 10^3 kg/hr) allowing for 20% oversized material at the 125 TPH (113.4 x 10^3 kg/hr) front end feed rate. The hogged wood discharge belt conveyor (L-2) which feeds the wood stacker assembly, (L-2) has a maximum capacity of 125 TPH (113.4 x 10^3 kg/hr). The sized energy wood from L-2 is received by the stacking conveyor, which is part of the hogged wood pile stacker/reclaimer assembly (L-3). The stacking conveyor with a capacity of 125 TPH (113.4 x 10^3 kg/hr) stacks an outdoor wood pile about 300 feet (91.4 m) wide by 300 feet (91.4 m) long and 30 feet (9.1 m) high. This pile holds about 14,800 tons (13.4 Mkg) of wood which is equivalent to about 2-1/2 months storage at the average boiler feed rate of 8.4 TPH (7.62 x 10^3 kg/hr). This provides sufficient storage during peak energy wood supply during summer months. The front end unloading system, from A-1 up to the stacking conveyor (L-3), operates only during energy wood deliveries scheduled five days a week, eight hours per day.

Energy wood is reclaimed from the pile with a bucket-wheel assembly which transports the chips down to a belt conveyor while traveling the span of the pile. The energy wood on the belt conveyor discharges onto a rotating bottom table that guides the energy wood to a tunnel belt conveyor (L-4). A schematic of the equipment associated with the wood storage [illegible] shown in Figure 7. The reclaimer operates at a maximum rate of [illegible] kg/hr), six days a week, eight hours per day. This [illegible] maintenance work on the front end wood handling system [illegible] a week without process interruption. The tunnel [illegible] wood to a disc screen (S-3) that separates [illegible] and fines are separately stored in live [illegible] separate storage, the amount of fines

in wood fuel fired can be controlled using weigh belt conveyors (L-7 and L-8) at the discharge end of each bin. In the event of discharge mechanism malfunction at the live bins, bin loading conveyors (L-5 and L-6) are equipped with by-pass chutes that supply energy wood to the weigh belts directly.

The fines storage bin (B-1) is sized for a 100 ton (90.72 x 10^3 kg) capacity. This provides 24 hours storage at the average fuel feed rate. The fines are discharged from the bin (B-1) through a live bottom hopper at an average rate of 1.7 TPH (1.52 x 10^3 kg/hr) to the weigh belt conveyor (L-7). The weigh belt is used to control the quantity of fines fed to the boiler. From the weigh belt conveyor (L-7), the fines are conveyed to the boiler by the wood fuel belt conveyor (L-9).

The wood chips from the separator (S-3) are conveyed to the wood chips storage bin (B-2) by the wood chips discharge belt conveyor (L-5). The chips storage bin is sized to hold 200 tons (181.43 x 10^3 kg), providing a 24 hour capacity at average operating rates. The conveyor feeding the bin (L-5) is sized to fill the bins in an eight hour period. The chip storage bin (B-2) discharges energy wood at a rate of 12 TPH (10.88 x 10^3 kg/hr) to the weigh belt conveyor (L-8) which monitors the feed rate of wood chips to the boiler. The wood chips from the weigh belt conveyor (L-8) discharge to the wood fuel belt conveyor (L-9) where they are combined with the fines from the fine weigh belt conveyor (L-7). The wood fuel belt conveyor (L-9) feeds wood to the boiler. The process flow diagram illustrating the front end wood handling system is presented in Figure 7 (Dwg NSTL-2).

Ash Removal System

The bottom ash is stored in a flooded hopper designed for an eight hour storate capacity. Once each eight hour shift the fly ash and bottom ash are discharged and hydraulically transported from the hoppers to the dewatering bin at regular intervals at a rate of 10 TPH (9.07 x 10^3 kg/hr) dry basis. Conveying water overflows and drains from the bin into the weir trough and the dewatering elements inside the bin give the final thorough drainage necessary to obtain commercially dry ash (20-50% water). All of the drain water discharges to the storage, recirculating and settling tank. Water from the settling tank is pumped back for re-use with no water wasted to sewer. Make-up water is limited to the quantity absorbed by the ash and lost by evaporation. Dewatered ash is discharged into waiting dump trucks for delivery to the Forest Management Contractor for possible use as soil conditioner. The ash contains potash and potassium which is beneficial to the potassium deficient soil at NSTL.

Fines settling in the recirculating tank are periodically discharged to the dewatering bin making the system self-cleaning. The process flow diagram for the ash handling system is shown in Figure 8 (Dwg NSTL-3).

Boiler Feedwater System

The boiler feedwater system depicted in Figure 9 provides deaerated treated water to the boiler. Condensate at 250°F (121°C) is returned to the deaerator column (V-2) from the condensate return pump (P-5A). The

deaerator operates at 15 psig (.20 MPa) and 250°F (121°C) flashing inert gases to the atmosphere through a control valve which maintains the 15 psig (.20 MPa) pressure at the deaerator column. The deaerator column is de-designed for 30 psig (.31 MPa) pressure and full vacuum at 300°F (149°C) and will remove dissolved oxygen in excess of .005 cc/liter from the feedwater. The deaerator column (V02) is supplied with a horizontal storage tank directly below the column which provides a ten minute surge capacity at full rate. A level controller on the storage tank controlls the flow of condensate to the deaerator from the condensate pumps (P-5A-C). In the event of a high level in V-2, the level controller opens a valve to allow the boiler feedwater to return to the condensate storage tank (T-5).

The pH of the boiler feedwater is maintained at the 9-10 range by the automatic injection of anhydrous ammonia from cylinders into the deaerator storage drum. A conductivity analyzer, used for pH measurement, controls the flow of ammonia into V-2. An oxygen analyzer monitors the oxygen content of the boiler feedwater which is controlled by the injection of sodium sulfite, an oxygen scavenger. A 10% solution of sodium sulfite and demineralized water is made up in the mix tank (T-1). The mix tank (T-1) holds about 30 gallons (.11 m^3) which allows for about a three day supply of solution at average operating rates. The solution is injected into the suction line of the boiler feedwater pumps with a metering pump (P-3). The flow of sulfite solution is controlled by measuring the boiler feedwater flow to the boilers with a flow controller which in turn regulates the speed and stroke controls on the injection pumps (P-3). The injection pump is designed for flows ranging from 2 to 12 gpm (.45 to 2.72 m^3/hr) to maintain a Na_2SO_3 level of 40 ppm in the feedwater to the boilers.

Three two-stage, 3600 RPM boiler feedwater pumps (P-2A-C) transfer the boiler feedwater at 15 psig (103 MPa) and 250°F (121°C) to the steam drums of the steam generators. Each pump has a 75 gpm (17.0 m^3/hr) capacity. The process flow diagram for the Boiler Feedwater System is shown in Figure 9 (Dwg NSTL-4).

Hot Water Generation System

Steam generated from the boiler (SG) is delivered at the cascade heater (E-1), as proposed by the International Boiler Works with a 10 psig (68.95 kPa) line loss. At daytime operating loads, 82,100 lb/hr (37,240 kg/hr) of 305 psig (2.20 MPa), 630°F (333°C) steam combines with 240°F (116°C) boiler feedwater at E-1 generating 449,150 lb/hr (203,730 kg/hr) of hot water at 400°F (205°C), 305 psig (2.20 MPa), The cascade heater (E-1) is provided with an expansion/water storage capability of 540 gallons (2.04 m^3). E-1 also functions as a deaerator for eliminating carbon dioxide and other gases raised in the boiler through the breakdown of salts. The water is finally divided into a multitude of streams, offering an infinite surface to the surrounding steam as it drops from tray to tray to break up temperature gradients, and to reform and provide new condensing surfaces to the steam. The height through which the water falls is designed for optimum contact time between steam and water. In order to keep high temperature water in the liquid state, system pressure is maintained by a steam cushion. The cascade heater (E-1) is provided with a relief valve that opens as pressure exceeds design pressure. A low

pressure signal will automatically feed E-1 with more steam maintaining a constant pressure. At the turndown rate, 38,000 lb/hr (17,236 kg/hr) of steam is condensed with 170,000 lb/hr (77,110 kg/hr) of boiler feedwater to meet the NSTL HTHW demand. The design duty of E-1 is 66.7 x 10^6 Btu/hr (19.54 MW) with a turndown design duty of 37.8 x 10^6 Btu/hr (11.08 MW). The cascade heater (E-1) is designed for a pressure of 350 psig (2.51 MPa).

Water Treatment and Condensate Storage

The regeneration cycle system uses 33% HCl and 50% NaOH for the cation and anion exchangers. The system uses .73 gallons (.0028 m^3) of HCl and .20 gallons (.001 m^3) of NaOH per 1000 gallons (3.78 m^3) of treated water generated. A 120 gallon (.45 m^3) tank (T-3) is provided for HCl storage and 120 gallon (.45 m^3) tank (T-4) is provided for NaOH storage. Both tanks are fiberglass reinforced polyester with a capacity for one month storage of chemicals at daytime operation. The spent regeneration chemicals go to the neutralizer tank (T-2) where the material can be held for one month prior to neutralization and disposal. The neutralizer tank (T-2) is underground and constructed of fiberglass reinforced polyester with a submerged pump (P-3) for recirculation and discharge. From DM the demineralized water goes to the condensate storage tank (T-5) which is a 9800 gallon (36 m^3) atmospheric tank constructed of carbon steel with a plastic lining to prevent metal contamination of the water. The condensate storage tank (T-5) collects and holds 449,100 lb/hr (203,707 kg/hr) of returned condensate from the NSTL heating loads plus the treated makeup water from the demineralizer unit (DM). The tank is vented to the atmosphere to allow for flashing steam from the returned condensate. Upon a low level signal from the level switch on T-5, the demineralizer unit will automatically start up and run for a minimum of three hours. A high level switch on T-5 signals DM to cease operation.

Hot Water Transmission System

Hot water for test site systems load equivalent to 37,700 lb/hr (17,100 kg/hr) is pumped (P-4A&B) through over two miles (3.2 km) of above ground pipeline, 4"ø (10.16 cm) with a 2-1/2" (6.35 cm) calcium silicate insulation. The pipes are laid on 1' (.30 m) to 3' (.91 m) high concrete sleepers. Two booster pumps are installed along the pipeline in the event of large pressure drops. The hot water delivered at the test site is circulated through existing pumps and pipeline.

The TAHP return condensate at 250°F (121°C) is pumped (P-7) back to the CHP through a separate pipeline over two miles (3.2 km) long, also 4" (10.16 cm) ø with a 2-1/2" (6.35 cm) calcium silicate insulation. The return condensate is stored in T-5.

Table H-1. NSTL/MSAAP Hot Water and Power Plant Equipment List

Item No.	Description	Installed Cost
A-1	Trailer Dumper with Live Bottom Hopper Dumper: 10'w x 40'l x 55° tilt angle Capacity: 125 TPH maximum Motor: 40 HP hydraulic drive Hopper: 14'w x 30'l x 20'h Capacity: 30 tons Bottom: 14'w x 40'l Capacity: 125 TPH Motor: 40 HP Ratchet Drive Conveyor Inc: pilings and concrete foundation	134,900
A-2	Hogger Dim: 95-1/2"w x 97-1/4"l x 82-1/2"h Feed opening: 51-1/4" x 47-1/2" Capacity: 25 TPH maximum Motor: 300 HP Inc: foundation, structure and electricals	100,000
A-3	Front End Loader Dim: 7'8"w x 17'11"l x 9'11"h x 34.8" min. reach Loader clearance circle: 33'3" Bucket: 84.5"w Bucket capacity: 100 ft^3 Shipping weight: 14,400 lbs Power requirement: 65 HP Inc: prime mover, oversized bucket, standard tires and equipments, lubricants, coolants	43,000
ASH-1	ASH Removal System Capacity: 10 TPH maximum Utility: 84 HP Inc: flooded bottom ash hopper, overflow seal box, sluice gate, sluice gate enclosure, spiral grinder assemblies,	480,000

Table H-1. (Continued)

Item No.	Description	Installed Cost
	slurry pumps, fly ash conveying system, water-exhaustors, air release chamber, boiler room pipe, fitting and control panel	
B-1	Fines Storage Bin Dim: 21'0"ø x 26'6"h With a 60° conical hopper 25'3"h Capacity: 100 tons Motor: 8 HP Inc: foundation, structure and electricals	119,500
B-2	Wood Chips Storage Bin Dim: 24'10"ø x 41'8"h With a 60° conical hopper 28'5"h Capacity: 200 tons Motor: 8 HP Inc: foundation, structure and electricals	198,000
D-1	Back Pressure Turbine/Generator Capacity: 2.5 MW Steam: 66,000 lb/H Inlet: 900 psig, 900°F Outlet: 235 psig, 630°F Duty: 7.6 MM Btu/H Inc: turbine, generator, gear, lube and oil system	800,000
DM-1	Water Treatment System Capacity: 7 GPM Dim: 2-8"ø x 6" TT Inc: 2-trains anion/cation demineralizer, carbon filters and pumps	58,600

Table H-1. (Continued)

Item No.	Description	Installed Cost
E-1	Hot Water Generator Desuperheater/ Condenser Area: 4,837 ft^2 ΔT_{LMTD}: 171.5°F Duty: 65 MM Btu/H Subcooler: Area: 167 ft^2 ΔT_{LMTD}: 81.47°F Duty: 6 MM Btu/H Inc: single pass, removable bundle with expansion joints, stainless steel tubes	75,800
HWT	TAHP Hot Water Transmission System Capacity: 88 GPM Dim: 4"ø x 12,360'l steel pipe with 2-1/2" thick calcium silicate insulation Inc: pipe, insulation, booster pumps, sleepers	250,000
L-1	Energy Wood Receiving Conveyor Dim: 42"w x 80'l x 14'h x 15° incline Capacity: 125 TPH maximum Motor: 12 HP Inc: motor, foundation, structure and electricals	64,000
L-2	Hogged Wood Discharge Belt Conveyor Dim: 42"w x 250'l x 40'h x 15° incline Capacity: 125 TPH maximum Motor: 20 HP Inc: motor, foundation, structure and electricals	212,500
L-3	Hogged Wood Pile Stacker/Reclaimer Assembly Stacker: 300'w x 300'l x 30' pile height Capacity: 125 TPH Motor: 5 HP	809,500

Table H-1. (Continued)

Item No.	Description	Installed Cost
	Transfer Belt: Dim: 42"w x 150'l Motor: 5 HP Shuttle Belt: Dim: 42"w x 150'l Motor: 7.5 HP Top Turntable: Dim: 12"ø Motor: 3 HP Shuttle Belt Carriage: Motor: 2 HP Reclaimer: Belt Conveyor: 24"w x 150'l Capacity: 30 TPH Motor: 10 HP	
	Concrete Pit: Dim: 24"ø x 10' deep Bucket Wheel Assembly Motor: 53 HP Inc: motor, 1-bucket wheel, 3-rakers, carriage drive, electric winch, floating cylinders, reclaimer rotation drive, bottom table, structure and electricals	50,000
L-4	Tunnel Belt Conveyor Dim: 24"w x 250'l x 14'h x 15° incline Capacity: 30 TPH Motor: 10 HP Conveyor speed: 300 FPM Inc: motor, concrete culvert, weather cover, structure and electricals	184,000
L-5	Wood Chips Discharge Belt Conveyor/ By-pass Chute Dim: 24"w x 260'l x 64'h x 15° incline with steel pipe chute 4"ø x 64'l Capacity: 20 TPH Motor: 7.5 HP Inc: motor, weather cover, foundation, structure and electricals	130,000

Table 3-32. (Continued)

Item No.	Description	Installed Cost
L-6	Fines Belt Conveyor/By-pass Chute Dim: 24"w x 210'l x 53'h x 15° incline With steel pipe 4"ø x 53'l Capacity: 10 TPH Motor: 5 HP Inc: motor, weather cover, foundation, structure and electricals	117,500
L-7	Fines Weigh Belt Conveyor Dim: 24"w x 27'l Capacity: 2 TPH Motor: 2 HP Inc: motor, weightometer, foundation, structure and electricals	33,000
L-8	Chips Weigh Belt Conveyor Dim: 24"w x 27'l Capacity: 14 TPH Motor: 5 HP Inc: motor, weightometer, foundation, structure and electricals	33,000
L-9	Wood Fuel Belt Conveyor Dim: 24"w x 162'l x 35'h x 15° incline Capacity: 14 TPH Motor: 10 HP Inc: motor, weather cover, foundation, structure and electricals	89,100
MX-1	Sodium Sulfite Mixer Motor: 1/2 HP	1,000
P-1 A&B	Blowdown Water Pump Capacity: 4 GPM Size: 1' x 1-1/2' x 6' Motor: 1/2 HP Speed: 1800 RPM Material: Ductile iron Inc: mechanical seal, coupling, motor	1,125

Table H-1. (Continued)

Item No.	Description	Installed Cost
P-2 A,B&C	Boiler Feedwater Pump Capacity: 75 GPM each Motor: 75 HP Speed: 3600 RPM Material: ductile iron turbine drive Inc: mechanical seal, couplings, by-pass heat exchanger, motor, turbine	53,750
P-3	Sodium Sulfite Injection Pump Capacity: 2 GPM ΔP: 15 psig 1/2 HP	500
P-4 A&B	TAHP Hot Water Pump Capacity: 55 GPM Head: 12' Motor: 1/2 HP Speed: 1800 RPM Material: Ductile iron Inc: mechanical seal, motor, coupling	2,000
P-5 A,B&C	Condensate Pump Capacity: 75 GPM Motor: 1 HP Speed: 3600 RPM Material: Ductile iron Inc: motor, mechanical seal, coupling, by-pass heat exchanger	2,400
P-6	Neutralizer Pump Capacity: 3 GPM ΔP: 35 psi Motor: 1/2 BHP	1,000
P-7 A,B&C	Return Condensate Pump Capacity: 550 GPM Motor: 5 HP Speed: 3600 RPM Inc: motor, mechanical seal, coupling, by-pass heat exchanger	15,000
P-8 A,B&C	TAHP Return Condensate Pump Capacity: 80 GPM each Motor: 1-1/2 HP	2,400

Table H-1. (Continued)

Item No.	Description	Installed Cost
PT-1	Overhead Power Transmission Line Capacity: 2.5 MW Voltage: 13.8 KV Inc: feeder, poles, overhead neutrals, 1351 MCM AL conductors, suspension bucket, spool bolts, downquys and discs	251,200
S-1	Cross Belt Electromagnetic Separator Dim: 48"w x 66"l x 14"h Motor: 10 HP Self cleaning Inc: motor, structure and electricals	30,000
S-2	Overs Disc Screen Dim: 4'0"w x 9'0"l x 3'6"h Capacity: 125 TPH Motor: 7.5 HP Inc: motor, foundation, structure and electricals	29,500
S-3	Fines Disc Screen Dim: 1'7"w x 12'7"l x 3'6"h Capacity: 30 TPH Motor: 5 HP Inc: motor, foundation, structure, and electricals	23,000
SG-1	Wood Fired Steam Generator Duty: 82 MM Btu/H Capacity: 66,000 lb/H Condition: 1000 psig, 905°F Inc: all pressure parts, including steam drums, furnace and convection tubing, feeder tubing and headers. All setting material including refractory tile, insulation and casing. Air heater, sootblowers, gas and air ducts, steam coil air preheater, duct insulation and lagging, forced draft fan and driver, induced draft fan and	2,000,000

Table H-1. (Continued)

Item No.	Description	Installed Cost
	driver, traveling grate spreader stoker with feeders and distributors, refractory (inc. ash hopper, plenum, and shiftings hopper), over-fire air system, cinder reinjection system, auxiliary oil burners and ignitors, combustion control and instrumentation, flame programming and protection system, valves, fittings, observation ports, access doors, and boiler trim, and complete gas cleaning system	
T-1	Sodium Sulfite Mix Tank Dim: 1'0"ø x 4'0" T-T x 5/16" thk Material: fiberglass reinforced polyester (Hetron 197)	2,500
T-2	Neutralizer Tank Dim: 2'6"ø x 9'6" T-T x 5/16" thk D.P.: 0 psig D.T.: 100°F Material: fiberglass reinforced polyester (Hetron 197)	10,000
T-3	HCl Storage Tank Dim: 2'6" x 6'0" T-T x 5/16" thk D.P.: 0 psig D.T.: 100°F Material: fiberglass reinforced polyester (Hetron 197)	9,000
T-4	NaOH Storage Tank Dim: 2'0"ø x 5'6" T-T x 5/16" thk D.P.: 0 psig D.T.: 100°F Material: fiberglass reinforced polyester (Hetron 197)	3,500

Table H-1. (Continued)

Item No.	Description	Installed Cost
T-5	Condensate Storage Tank Dim: 7'6"ø x 29'8" T-T x 5/16" thk D.P.: 0 psig D.T.: 250°F Material: fiberglass reinforced polyester (Hetron 197)	50,000
V-1	Blowdown Drum Dim: 1'ø x 5'0" T-T x 5/16" thk Weight steel: 220 lbs	650
V-2	Deaerator Operating pressure: 30 psia Dim: 5'6"ø x 5'0" TT vertical flash drum 6'0"ø x 14'0"TT horizontal storage drum Capacity: 15 min. storage Inc: spray scrubber	36,000
V-3	Recycle Flash Drum Dim: 2'ø x 13'6"l x 3/8" thk Weight steel: 1400 lbs	2,300

Table H-2. NSTL Hot Water Generator Equipment List

Item No.	Description	Installed Cost
A-1	Trailer Dumper with Live Bottom Hopper Dumper: 10'w x 40'l x 55° tilt angle Capacity: 125 TPH maximum Motor: 40 HP hydraulic drive Hopper: 14'w x 30'l x 20'h Capacity: 30 tons Bottom: 14'w x 40'l Capacity: 125 TPH Motor: 40 HP Ratchet Drive Conveyor Inc: pilings and concrete foundation	134,900
A-2	Hogger Dim: 95-1/2"w x 97-1/4"l x 82-1/2"h Feed opening: 51-1/4" x 47-1/2" Capacity: 25 TPH maximum Motor: 300 HP Inc: foundation, structure and electricals	100,000
A-3	Front End Loader Dim: 7'8"w x 17'11"l x 9'11"h x 34.8" min. reach Loader clearance circle: 33'3" Bucket: 84.5"w Bucket capacity: 100 ft^3 Shipping weight: 14,400 lbs Power requirement: 65 HP Inc: prime mover, oversized bucket, standard tires and equipments, lubricants, coolants	43,000
ASH	ASH Removal System Capacity: 10 TPH maximum Utility: 84 HP Inc: flooded bottom ash hopper, overflow seal box, sluice gate, sluice gate enclosure, spiral grinder assemblies,	480,000

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Table H-2. (Continued)

Item No.	Description	Installed Cost
	slurry pumps, fly ash conveying system, water-exhaustors, air release chamber, boiler room pipe, fitting and control panel	
B-1	Fines Storage Bin Dim: 21'0"ø x 26'6"h With a 60° conical hopper 25'3"h Capacity: 100 tons Motor: 8 HP Inc: foundation, structure and electricals	119,500
B-2	Wood Chips Storage Bin Dim: 24'10"ø x 41'8"h With a 60° conical hopper 28'5"h Capacity: 200 tons Motor: 8 HP Inc: foundation, structure and electricals	198,000
DM	Water Treatment System Capacity: 7 GPM Dim: 2-8"ø x 6" TT Inc: 2-trains anion/cation demineralizer, carbon filters and pumps	58,600
E-1	Hot Water Generator Capacity: 1000 GPM Storage Capacity: 540 gals Duty: 67 MM Btu/H Operating Weight: 14,100 lbs Steam Inlet: 305 psig, 426°F Water Inlet: 250°F Hot water outlet: 300 psig, 400°F Incl: The heater as offered incl. stainless steel perforated plate trays made up in sections which are removable through the manway,	41,500

Table H-2. (Continued)

Item No.	Description	Installed Cost
	hinged manway, 100% x-ray of weld joints, protective interior coating, interior access ladder, required shell connections for instrumentation, controls, etc., four point bearing brackets - support columns or structures by others, trim consisting of (trim shipped loose for field mounting by others): 1-6"dial pressure gauge with syphon and shutoff valve, 2-6"dial thermometers with 20'of capillary tubing, 1-water level gauge complete with associated valves, 1-mercoid type high level switch for remote alarm by others, 1-mercoid type low level switch for remote alarm by others, 1-set tandem blowdown valves, 1-safety relief valves; main connections: water supply -10" nominal-weld end, water return - 8" nominal-weld end, steam supply - 10"nominal-weld end.	
HWT	TAHP Hot Water Transmission System Capacity: 88 GPM Dim: 4"ø x 12,360'l steel pipe with 2-1/2" thick calcium silicate insulation Inc: pipe, insulation, booster pumps, sleepers	250,000
L-1	Energy Wood Receiving Conveyor Dim: 42"w x 80'l x 14'h x 15° incline Capacity: 125 TPH maximum Motor: 12 HP Inc: motor, foundation, structure and electricals	64,000
L-2	Hogged Wood Discharge Belt Conveyor Dim: 42"w x 250'l x 40'h x 15° incline Capacity: 125 TPH maximum Motor: 20 HP Inc: motor foundation, structure and electricals	212,500

Table H-2. (Continued)

Item No.	Description	Installed Cost
L-3	Hogged Wood Pile Stacker/Reclaimer Assembly Stacker: 300'w x 300'l x 30' pile height Capacity: 125 TPH Motor: 5 HP Transfer Belt: Dim: 42"w x 150'l Motor: 5 HP Shuttle Belt: Dim: 42"w x 150'l Motor: 7.5 HP Top Turntable: Dim: 12"ø Motor: 3 HP Shuttle Belt Carriage: Motor: 2 HP Reclaimer: Belt Conveyor: 24"w x 150'l Capacity: 30 TPH Motor: 10 HP	809,500
	Concrete Pit: Dim: 24"ø x 10' deep Bucket Wheel Assembly Motor: 53 HP Inc: motor, 1-bucket wheel, 3-rakers, carriage drive, electric winch, floating cylinders, reclaimer rotation drive, bottom table, structure and electricals	50,000
L-4	Tunnel Belt Conveyor Dim: 24"w x 250'l x 14'h x 15° incline Capacity: 30 TPH Motor: 10 HP Conveyor speed: 300 FPM Inc: motor, concrete culvert, weather cover, structure and electricals	184,000
L-5	Wood Chips Discharge Belt Conveyor/ By-pass Chute Dim: 24"w x 260'l x 64'h x 15° incline with steel pipe chute 4"ø x 66'l Capacity: 20 TPH Motor: 7.5 HP Inc: motor, weather cover, foundation, structure and electricals	130,000

Table H-2. (Continued)

Item No.	Description	Installed Cost
L-6	Fines Belt Conveyor/By-pass Chute Dim: 24"w x 210'l x 53'h x 15° incline With steel pipe 4"ø x 53'l Capacity: 10 TPH Motor: 5 HP Inc: motor, weather cover, foundation, structure and electricals	117,500
L-7	Fines Weigh Belt Conveyor Dim: 24"w x 27'l Capacity: 2 TPH Motor: 2 HP Inc: motor, weightometer, foundation, structure and electricals	33,000
L-8	Chips Weigh Belt Conveyor Dim: 24"w x 27'l Capacity: 14 TPH Motor: 5 HP Inc: motor, weightometer, foundation, structure and electricals	33,000
L-9	Wood Fuel Belt Conveyor Dim: 24"w x 162'l x 35'h x 15° incline Capacity: 14 TPH Motor: 10 HP Inc: motor, weather cover, foundation, structure and electricals	89,100
MX	Sodium Sulfite Mixer Motor: 1/2 HP	1,000
P-1 A&B	Blowdown Water Pump Capacity: 5 GPM Size: 1' x 1-1/2' x 6' Motor: 1/2 HP Speed: 1800 RPM Efficiency: 50% Material: Ductile iron Inc: mechanical seal, coupling, motor	1,125

Table H-2. (Continued)

Item No.	Description	Installed Cost
P-2 A,B,&C	Boiler Feedwater Pump Capacity: 90 GPM each Drivers: 25 HP Speed: 3600 RPM Material: ductile iron 1 turbine drive/2 motor drive Inc: mechanical seal, couplings, by-pass heat exchanger, motor, turbine	53,750
P-3	Sodium Sulfite Injection Pump Capacity: 2 GPM Motor: 1/2 HP Speed: 1800 RPM	500
P-4 A&B	TAHP Hot Water Pump Capacity: 55 GPM Head: 12' Motor: 1/2 HP Speed: 1800 RPM Material: Ductile iron Inc: mechanical seal, motor, coupling	2,000
P-5	Neutralizer Pump Capacity: 3 GPM ΔP: 35 psi Motor: 1/2 BHP	1,000
P-6 A,B&C	Condensate Pump Capacity: 500 GPM Motor: 110 HP Speed: 3600 RPM Material: Ductile iron Inc: motor, mechanical seal, coupling, by-pass heat exchanger	15,000
P-7 A,B&C	TAHP Return Condensate Pump Capacity: 80 GPM Motor: 1/2 HP Speed: 1800 RPM Inc: motor, mechanical seal, coupling, by-pass heat exchanger	2,400

Table H-2. (Continued)

Item No.	Description	Installed Cost
S-1	Cross Belt Electromagnetic Separator Dim: 48"w x 66"l x 14"h Motor: 10 HP Self cleaning Inc: motor, structure and electricals	30,000
S-2	Overs Disc Screen Dim: 4'0"w x 9'0"l x 3'6"h Capacity: 125 TPH Motor: 7.5 HP Inc: motor, foundation, structure and electricals	29,500
S-3	Fines Disc Screen Dim: 1'7"w x 12'7"l x 3'6"h Capacity: 30 TPH Motor: 5 HP Inc: motor, foundation, structure, and electricals	23,000
SG	Wood Fired Steam Generator Duty: 82 MM Btu/H Capacity: 82,000 lb/H Condition: 330 psig, sat. Inc: all pressure parts, including steam drums, furnace and convection tubing, feeder tubing and headers. All setting material including refractory tile, insulation and casing. Air heater, sootblowers, gas and air ducts, steam coil air preheater, duct insulation and lagging, forced draft fan and driver, induced draft fan and driver, traveling grate spreader stoker with feeders and distributors, refractory (inc. ash hopper, plenum, and shiftings hopper), over-fire air system, cinder reinjection system, auxiliary oil burners and ignitors, combustion control and instrumentation, flame programming and	1,800,000

Table H-2. (Continued)

Item No.	Description	Installed Cost
	protection system, valves, fittings, observation ports, access doors, and boiler trim, and complete gas cleaning system	
T-1	Sodium Sulfite Mix Tank Dim: 1'0"ø x 4'0" T-T x 5/16" thk Material: fiberglass reinforced polyester (Hetron 197)	2,500
T-2	Neutralizer Tank Dim: 2'5"ø x 9'7" T-T x 5/16" thk D.P.: 0 psig D.T.: 100°F Material: fiberglass reinforced polyester (Hetron 197)	10,000
T-3	HCl Storage Tank Dim: 2'0"ø x 5'0" T-T x 5/16" thk D.P.: 0 psig D.T.: 100°F Material: fiberglass reinforced polyester (Hetron 197)	9,000
T-4	NaOH Storage Tank Dim: 2'0"ø x 5'0" T-T x 5/16" thk D.P.: 0 psig D.T.: 100°F Material: carbon steel w/ plastic lining	3,500
T-5	Condensate Storage Tank Dim: 9'6"ø x 18'6" T-T x 5/16" thk D.P.: 0 psig D.T.: 250°F Material: fiberglass reinforced polyester (Hetron 197)	50,000
V-1	Blowdown Drum Dim: 1'ø x 5' T-T x 5/16" thk Weight steel: 220 lbs	650
V-2	Deaerator Operating pressure: 25 psia Dim: 5'6"ø x 5'0" TT vertical flash drum 6'0"ø x 14'0"TT horizontal storage drum Capacity: 15 min. storage Inc: spray scrubber	36,000

MSAAP Biomass Steam Process Description

The MSAAP Biomass Steam Plant is divided into six systems similar to the two NSTL Plants. The front end wood handling system is identical to the system described for the NSTL plants except that the chips storage bins are sized to hold 110 tons (99.8 x 10^3 kg) each, providing 30 hours capacity at maximum operating rates. Each storage bin discharges 3.5 TPH (3.18 x 10^3 kg/hr) to each of four weigh belt conveyor (L-8A-D) which control the feed rate of wood chips to the boiler.

Steam Generation System

Four wood-fired steam generators are provided. The boilers (SG-1, 2, 3, & 4) are used in conjunction with the waste heat boilers provided with the diesel generators. The steam generators provided 132,000 lb/hr (59,874 kg/hr) saturated steam at 130 psig (1.0 MPa) and the waste heat boilers provide 21,750 lb/hr (9866 kg/hr) steam. The steam generators each have an output duty of 32 million Btu/hr (9.38 MW), generating 32,950 lb/hr (14,946 kg/hr) of steam with a fired duty of 46.8 million Btu/hr (13.72 MW). Each boiler requires 5.22 TPH (4.74 x 10^3 kg/hr) wood feed at maximum capacity operating at an overall efficiency of 68%. Boiler feedwater from the boiler feedwater pumps (P-1A-D) is fed to the steam drum of the steam generators at 259°F (126°C) and about 150 psig (1.14 MPa). The feedwater to each boiler is received from a common header and the level in each steam drum is maintained by controlling the feed of water to the drum. A flow controller on the main steam line from the steam drum measures changes in steam flow and senses level changes in the steam drum, then provides a set point signal for the steam drum level controller. The steam generated at each boiler at 130 psig (1.0 MPa) and 356°F (180°C) enters a common header system which routes the steam to the process and heating steam users. Because of the high quality of the boiler feedwater, blowdown is assumed to be only 1% of the steam generated. The continuous blowdown from the steam drum is flashed to 20 psig (.24 MPa) in the blowdown drums (V-1, 2, 3, & 4) where the flashed steam is sent ot the 20 psig (.24 MPa) steam system and the condensate is purged from the system. A level controller maintains a level in each blowdown drum by controlling the flow of condensate from the drum. The blowdown water can be sewered or sent to the cooling tower as part of its make-up water requirements.

Each steam generator is provided with a forced draft fan to supply combustion air, which is preheated in the air preheater by exchange with the flue gases. The flue gases are withdrawn from the steam generators by an induced draft fan. Fly ash and fly carbon are first separated from the flue gases by mechanical separators followed by an electrostatic precipitator in order to meet federal and local particulate specifications. The fly carbon and fly ash are separated and the fly carbon is reinjected into the combustion chamber. From the electrostatic precipitators the flue gases are routed to a common stack. Each boiler is provided with sootblowers, controls, traveling grate spreading stokers, ash hoppers, refractory, boiler trim, and auxiliary oil burners and ignitors. The process flow diagrams for the steam generation system are depicted in Figures 19 and 20.

Ash Removal System

Each boiler system has an ash removal system (ASH 1, 2, 3, & 4) connected to a common system for ash dewatering and removal (ASH-5) which include the water circulating pumps and make-up water pumps as well as a settling tank and dewatering bin. ASH-5 handles 10 tons/hr (9.1 x 10^3 kg/hr) ash on a dry basis. With four boilers operating at maximum capacity the normal rate of ash generation will be about one ton per hour (907 kg/hr) allowing for intermittant operation of the ash removal system. The dewatered ash containing 20 to 50% moisture is stored in the ash storage silo (T-1) which is designed for ten days ash storage. From the ash storage silo the ash is removed to disposal by trailer. The process flow diagram for the ash handling systems are shown in Figures 19 and 20.

Boiler Feedwater System

Condensate at 177°F (80.6°C) is returned to the deaerator column V-5) from the condensate return pumps (P-4A-C). The deaerator operates at 20 psig (.24 MPa) and 259°F (126°C) heating the cold condensate to 259°F (126°C) with 20 psig steam entering at the bottom of the sieve tray column. Inert gases driven from the condensate are vented to the atmosphere through a control valve which maintains the 20 psig pressure at the deaerator column. The deaerator column is designed for 30 psig (.31 MPa) pressure and full vacuum at 300°F (149°C) and will remove dissolved oxygen in excess of .005 cc/liter from the feedwater. Directly below the deaerator column (V-5) is the deaerator storage tank (V-6) which provides a ten minute surge capacity at full rate. A level controller on the storage tank controls the flow of condensate to the deaerator from the condensate pumps (P-4A-C). In the event of a high level in V-6 the level controller opens a valve to allow the boiler feedwater to return to the condensate storage tank (T-6).

The pH of the boiler feedwater is maintained in the 9-10 range by the automatic injection of anhydrous ammonia from cylinders into the deaerator storage drum. The system is equipped with a conductivity analyzer and an oxygen analyzer. A 10% solution of sodium sulfite and demineralized water is made up in a mix tank (T-2) which holds about 360 gallons (1.36 m^3) or about a three day supply of solution at full operating rate.

Four two-stage, 3600 RPM boiler feedwater pumps (P-1A-D) transfer the boiler feedwater at 20 psig (.24 MPa) and 259°F (126°C) to the steam drums of the steam generators. Two of the pumps are motor driven and two are driven with steam turbines using 130 psig (1.0 MPa) inlet steam and exhausting to the 20 psig (.24 MPa) steam header. Under full load conditions two motor driven and one turbine driven pumps will be in operation with the fourth pump as a spare. Each pump is provided with a minimum flow bypass, controlled by a restriction orifice, which recirculates the water back to the deaerator. Each pump has a 130 gpm (29.5 m^3/hr) capacity with a discharge pressure of about 180 psig (1.3 MPa).

Water Treating and Condensate Storage

The required make-up at full operating rate is 33,460 lb/hr (15,177 kg/hr). The demineralizer unit DM-1 is designed to operate at 175 gpm (39.73 m^3/hr) producing 120,000 gallons (454 m^3) of treated water between regenerations. Under these conditions water of the following quality will be produced:

1.5 ppm cation

1.5 ppm anion

0.2 ppm silica (as SiO_2)

The system will be capable of regeneration in a four hour period. For the regeneration cycle the system uses 33% HCl and 50% NaOH for the cation and anion exchangers. The system uses .73 gallons (.0028 m^3) of HCl and .30 gallons (.0011 m^3) of NaOH per 1000 gallons (3.79 m^3) of treated water generated. A 2130 gallon (8.06 m^3) tank (T-4) is provided for HCl storage and an 896 gallon (3.39 m^3) tank (T-5) is provided for NaOH storage.

The condensate storage collects and holds the 115,240 lb/hr (52,272 kg/hr) of returned condensate from the heating and process steam users plus the treated make-up water when the demineralizer is in operation. The tank is vented to the atmosphere to allow for flashing steam from the returned condensate. The condensate storage tank will hold enough water for up to 14 hours of boiler operation at full rate with the demineralizer out of service. Upon a low level signal from the level switch on T-6, the demineralizer unit will automatically start up and run for a minimum of two hours. A high level switch on T-6 signals DM-1 to cease operation. After approximately 13 hours operation of DM-1 the system will be shut down for about four hours for regeneration. During this time makeup water to the deaerator is supplied by the condensate stored in T-6. The condensate from T-6 is returned to the deaerator by the condensate return pumps (P-4A-C) using two pumps when operating at maximum rate with one pump as a spare. One of the pumps is driven by a back pressure steam turbine using 130 psig (1.0 MPa) inlet steam exhausting to the 20 psig (.24 MPa) steam header. The pumps are designed for 175 gpm (39.7 m^3/hr) each with a discharge pressure of 50 psig (.45 MPa). Recirculation lines back to T-6 are provided to meet the minimum flow requirements of the pumps. The flow of water back to the deaerator is controlled by a level controller at the deaerator. The water treating and condensate storage system is shown in Figure 23 (DWG. MSAAP-7).

Table H-3. MSAAP Equipment List

Item	Description	Installed $1000
A-1	Trailer Dumper w/live bottom hopper Dumper: 10'w x 40'l w/55° tilt angle capacity 125 TPH 40 HP, Hydraulic drive Hopper: 14'w x 30' l x 20'h 30 ton capacity Bottom Feeder: capacity 125 TPH 40 HP Price includes pilings and concrete foundations	134.9 (1)
A-2	Wood Hogger 25 TPH capacity, 300 HP	100 (1)
A-3	Front End Loader Bucket capacity 100 ft^3	43 (1)
ASH-1	SG-1 Ash Handling Package recirculating closed circuit fly ash and bottom ash sluice system. Includes: Flooded bottom ash hopper, overflow seal box, sluice gate, sluice gate enclosure, spiral grinder assemblies, fly ash hopper and fly ash sluice tank, slurry pumps, piping, fittings, and control panel	36.75
ASH-2	SG-2 Ash Handling Package	36.75
ASH-3	SG-3 Ash Handling Package	36.75
ASH-4	SG-4 Ash Handling Package	36.75
ASH-5	Common Ash Removal System capacity: 10 TPH max 84 HP Includes: Settling tank, de-watering bin, overflow sump, water supply and circulating pumps, piping, fittings, and control panel	320
B-1 A,B,C,&D	Wood Fines Storage Bin 4 required 55 T capacity each 5 HP each	312 (1)

Table H-3. (Continued)

Item	Description	Installed $1000
B-2 A,B,C,&D	Wood Chips Storage Bin 4 required 110 T capacity each 5 HP each	476[1]
DM-1	Demineralizer Unit anion/cation unit with carbon filters and pumps 175 GPM capacity 10 HP	344
L-1	Wood Receiving Conveyor 42" w x 80' l, 15° incline 125 TPH capacity 10 HP	64[1]
L-2	Hogged Wood Discharge Belt Conveyor 42"w x 250'l x 60'h 15° incline w/weather cover 105 TPH capacity 20 HP	191[1]
L-3	Hogged Wood Pile Stacker/ Reclaimer Assembly Includes: Stacker, transfer belt, shuttle belt, top turntable, shuttle belt carriage, reclaimer belt conveyor, concrete pit, and bucket wheel assembly 125 TPH capacity 90 HP	900[1]
L-4	Tunnel Belt Conveyor 42"w x 250'l, 15° incline 105 TPH capacity 20 HP Tunnel 10'ø x 200'l	275.3[1]
L-5 A,B,C,&D	Wood Chips Discharge Belt Conveyor/Bypass Chute 4 required 24"w x 250'l 17 TPH each 7.5 HP each	468[1]

Table H-3. (Continued)

Item	Description	Installed $1000
L-6 A,B,C,&D	Fines Belt Conveyor/Bypass Chute 4 required 24" w x 250' l 8.5 TPH each 5 HP each	417.2[1]
L-7 A,B,C,&D	Fines Weigh Belt Conveyor 4 required 24"w x 27'l 2 TPH capacity each 2 HP each	140[1]
L-8 A,B,C,&D	Chips Weigh Belt Conveyor 4 required 24"w x 27'l 4 TPH capacity each 5 HP each	140[1]
L-9 A,B,C,&D	Wood Fuel Belt Conveyor 4 required 24"w x 150'l 6 TPH capacity each 10 HP each	240[1]
MX-1	Sodium Sulfite Drum Mixer 1/2 HP	1
P-1 A,B,C,&D	Boiler Feedwater Pumps 3 operating/1 spare 2 w/turbine drivers 2 w/motor drivers 130 GPM, ΔP=150 psi 3600 RPM, 2 stage 16 BHP each	50.1
P-2 A&B	Sodium Sulfite Injection Pump 1 operating/1 spare 12 GPH, ΔP=40 psi with motor and flow controls 1/4 BHP each	5.8
P-3	Neutralizer Pump 50 GPM, ΔP=35 psi w motor 2 BHP	4.2

Table H-3. (Continued)

Item	Description	Installed $1000
P-4 A,B,&C	Condensate Pumps 2 operating/1 spare 1 turbine drive 2 motor drive 175 GPM, ΔP=50 psi 8.5 BHP each	25.9
S-1	Cross Belt Electromagnetic Separator 48"w x 66"l x 14"h 10 HP	30(1)
S-2	Overs Disc Screen 4'0"w x 9'0"l x 3'6"h 125 TPH capacity 7.5 HP	29.5(1)
S-3	Fines Disc Screen 105 TPH capacity 10 HP	30(1)
SG-1	Wood-Fired Steam Generator Fired duty: 46.8 MM Btu/Hr Capacity: 33,000 lb/Hr steam 130 psig, sat'd Includes: All pressure parts, including steam drums, furnace and convection tubing, feeder tubing and headers. All setting material including refractory tile, insulation and casing. Air heater. Sootblower, gas and air ducts, steam coil air pre-heater, duct insulation and lagging, forced draft fan and driver, traveling grate spreader stoker with feeders and distributors, refractory (incl. ash hopper, plenum, and siftings hopper), over-fire air system, cinder reinjection system, auxiliary oil burners and ignitors, combustion control and instrumentation, flame programming and protection system, valves, fittings, observation ports, access doors, and boiler trim, and complete gas cleaning system	1,286

Table H-3. (Continued)

Item	Description	Installed $1000
SG-2	Wood-Fired Steam Generator (same as SG-1)	1,286
SG-3	Wood-Fired Steam Generator (same as SG-1)	1,286
SG-4	Wood-Fired Steam Generator (same as SG-1)	1,286
ST-1 A&B	Boiler Feedwater Pump Steam Turbines 2 required 130 psig inlet 20 psig exhaust 16 BHP rating @ 3600 RPM	as P-1
ST-2	Condensate Pump Steam Turbine 130 psig inlet 20 psig exhaust 8.5 BHP rating	as P-4
T-1	Ash Storage Silo 24'10" x 36'6" Carbon Steel	105.8
T-2	Sodium Sulfite Mix Tank 3'6"ø x 6'0" x 3/8" thk Material - Fiberglass reinforced polyester (Hetron 197)	5.7
T-3	Neutralizer Tank 5'0"ø x 20'0" T-T x 3/8" thk D.P. 0 psig D.T. 100°F Material - Fiberglass reinforced polyester (Hetron 197)	18
T-4	HCL Storage Tank 5'0"ø x 13'6" T-T x 5/8" thk D.P. 0 psig D.T. 100°F Material - Fiberglass reinforced polyester (Hetron 197)	16.4

Table H-3. (Continued)

Item	Description	Installed $1000
T-5	NaOH Storage Tank 3'6"ø x 11'9" T-T x 3/8" thk D.P. 0 psig D.T. 100°F Material - Fiberglass reinforced polyester (Derakane 411-45)	8.6
T-6	Condensate Storage Tank 17'0"ø x 35'0" T-T x 3/8" thk D.P. 0 psig D.T. 250°F Material - Carbon steel w/ plastic lining	160.8
V-1	Blowdown Drum (SG-1) 2'6"ø x 5'0" T-T x 7/16" thk D.P. 30 psig + full vacuum D.T 300°F Material - Carbon steel w/ 1/4" C.A.	5.6
V-2	Blowdown Drum (SG-2) (same as V-1)	5.6
V-3	Blowdown Drum (SG-3) (same as V-1)	5.6
V-4	Blowdown Drum (SG-4) (same as V-1)	5.6
V-5	Deaerator 5'0"ø x 10'0" T-T x 9/16" thk D.P. 30 psig + full vacuum D.T. 300°F Material - Carbon steel w/ 1/4" C.A.	21.9
V-6	Deaerator Storage Tank 6'6"ø x 15'11" T-T x 9/16" thk D.P. 30 psig + full vacuum D.T. 300°F Material - Carbon steel w/ 1/4" C.A.	36

Table H-3. (Continued)

Item	Description	Installed $1000
V-7	Header Condensate Flash Drum 2'6"ø x 6'6" T-T x 5/16" thk D.P. 0 psig D.T. 300°F Material - Carbon steel w/ 1/4" C.A. Demister mesh included	3
V-8	Process Condensate Flash Drum 4'0"ø x 12'0" T-T x 9/16" thk D.P. 30 psig + full vacuum D.T. 375°F Material - Carbon steel w/ 1/4" C.A. Demister mesh included	16.2
V-9	Heating Condensate Flash Drum 4'6"ø x 13'0" T-T x 9/16" thk D.P. 30 psig + full vacuum D.T. 375°F Material - Carbon steel w/ 1/4" C.A. Demister mesh included	19.2
	Total Installed Equipment Cost (1979 $)	6,476.0(2)
	Total Plant Investment (1979 $) Front End Wood Handling System	3,990.9(1)

Notes

(1) Equipment costs represent a supplier quoted total plant investment cost including engineering and design, contractors profit and overheads, and contingency.

(2) Excludes equipment which is part of the front end wood handling system shown on Dwg MSAAP-2 (Figure 3-20) and described in Note (1) above.

Table H-4. Sources of Equipment Cost Information

Ash Removal System	North Associates United Conveyors
Cascade Heater	International Boiler Works
Conveyors	Bulk Handling Systems, Inc. Rader Systems
Disc Screen	Rader Systems
Harvesting/Chipping (Tree)	L. B. Foster Co. Morbark Industries Nicholson Manufacturing Precision Chipper
Front End Loader	Caterpillar
Hogger	Jeffrey Manufacturing Division, Dresser Industries Inc.
Hot Water Transmission System	Parks-Cramer Co Rust Engineering
Line Storage	Wellons Inc.
Pile Storage	Rader Systems
Power Transmission System	Mississippi Power Co.
Pumps	Goulds Pump Ingersoll-Rand Co. Bingham Willamette
Shell and Tube Heat Exchanger	Southwestern Engineering Co. American-Standard, Heat Transfer Division
Steam-Turbine Generator	Trane Terry Corp.
Water Treatment System	LA Water Treatment
Wood Fired Steam Generator	Combustion Engineering Detroit Stokers Foster Wheeler Energy Corp Riley Stokers

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